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WRAP a model for regional solid waste management planning

user's guide

PB 266 220

a current report on solid waste management

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This document comprises the User's Guide, which is addressed to the individual, or group of individuals who are intended to use the WRAP model to assist in the decision-making process. The model is fully described in terms of its makeup and equation structure to familiarize the users with its capabilities. The guide additionally contains a full description of the kinds of data required for its use, as well as how to prepare and utilize those data and how to interpret outputs. Examples of prepared data inputs are provided as well as a guide to the design and operation of the model.

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WRAP

A MODEL FOR REGIONAL SOLID WASTE MANAGEMENT PLANNING

User's Guide

This report (SW-573) was prepared for the Office of Solid Waste
by Edward B. Berman and staff,
under the direction of Donna M. Krabbe

U.S. ENVIRONMENTAL PROTECTION AGENCY
1977

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CHAPTER 1

THE WRAP MODEL

What to do with the millions of tons of solid waste produced annually throughout the country creates difficult decisions that must be addressed at local levels. These decisions, which were once rather straightforward, are now complicated by the increasing costs of disposal, new technologies, environmental regulations, and the unavailability of land for landfill. These factors facing local decision makers give rise to strong pressures towards the regionalization of solid waste management functions. However, regionalization itself creates two fundamental problems: the complexity of the regional system design; and a problem of political consensus amongst the participants. Both of these problems have to be addressed by developing and clearly presenting technical and economic data about the consequences of various regional approaches.

To assist decision makers who are considering the implementation of regional solid waste management functions, the U.S. Environmental Protection Agency has sponsored the development of a computer model called WRAP (Waste Resources Allocation Program). Based upon data inputs provided by the users, WRAP sorts out the various options and indicates a preferred solution which is the minimum cost regional plan that meets all the constraints determined by its users. Use of the model enables officials to study and analyze the costs and implications of all available alternatives under consideration. By using WRAP, decision makers can find answers to such questions as: Which technology should be selected? Where should the facility and subscribing transfer stations be located? Whom should they serve? How large should they be? What will a system that meets all the objectives cost? What are good alternatives and what will they cost? In sum, what is the most economically preferred regional system design and what are the costs associated with changing that design?

A key capability of WRAP is its ability to balance the economies of scale achievable through centralization of processing at one location against the additional haul costs required for centralization. This makes it possible to determine what levels of centralization make the most economic sense.

WRAP consists of a series of equations which consider the sources of solid waste generation over a given planning region, a set of sites, and processes to be considered at those sites, as well as various site and process capacity constraints. The processes can be transfer stations, resource recovery processes (including the extraction of recoverable resources to be marketed), secondary processes (which receive the residue of primary processes as input) and various disposal processes. WRAP further considers many transportation route alternatives from sources of waste generation to sites, and from sites to sites, with due allowance for site traffic constraints.

Processing costs are input to WRAP so as to reflect the economies of scale available for each process, and revenues from the marketing of recovered materials. Haul costs are included, which increase directly which both tonnage and travel time.

WRAP has three essential components:

structure - which assures that each alternative considered is feasible in the sense that all wastes generated are entered into transportation, that all wastes arriving at a site are processed, that all residues generated are processed at the site or entered into transportation, that no process exceeds the indicated tonnage maximums, and that traffic constraints are observed;

cost - which assures that each alternative is properly costed, including economies of scale where appropriate; and

procedure - an organized mathematical search which allows those options which improve the solution to be separated from those that make it worse, and indicates when the least cost solution has been identified.

To date, the WRAP model has been used in several locations by decision makers who are considering regional solid waste management. In Massachusetts, the model was used to identify the most efficient regional system design for that state's first regional resource recovery system. And in St. Louis, Missouri, WRAP was used to determine the advantages of community participation in a proposed regional solid waste management plan.

Comprehensive information that describes and documents the use of the WRAP model is available to potential users. This information comprises three volumes: A User's Guide; A Programmer's Manual; and a full documentation of the model applications made for EPA.

This document comprises the User's Guide, which is addressed to the individual, or group of individuals, who are intending to use the WRAP model to assist in the decision-making process. The model is fully described in terms of its makeup and equation structure to familiarize the users with its capabilities. The guide additionally contains a full description of the kinds of data required for its use, as well as how to prepare and utilize those data and how to interpret outputs. Examples of prepared data inputs are provided, as well as a guide to the design and operation of the model.

For further information about the WRAP model, call or write:

Office of Solid Waste Management Programs
ATTN: Systems Management Division (AW-464)
U.S. Environmental Protection Agency
Washington, D.C. 20460
Telephone (202) 755-9125

CHAPTER 2

DETAILED MODEL DESCRIPTION

Model Background

WRAP is a fixed-charge linear programming model, using as the optimizer an algorithm developed by Dr. Warren Walker.[1]

The fixed-charge capability of the model permits the representation of economies of scale in process costs. Figure 1 illustrates a concave total cost function, typical of solid waste processing, as represented by several linear segments. Since the model is cost-minimizing, it will seek out the lowest cost segment at any level of tonnage. Thus the capability of treating cost in two parameters (fixed and variable, or intercept and slope) permits the model to represent economies of scale at any level of accuracy desired. In the actual model applications, three-segment representations have been used for nearly all processes.

Model Overview

The model operates in two modes:

A. Static

B. Dynamic

In the dynamic mode, the total planning period is divided into from two to four model periods. The model periods may each be any integer number of years which add up to the planning period.

The model has a pre-processor, an optimizer, and a post-processor as shown in Figure 2. Note that the pre-processor and post-processor differentiate between the static and dynamic modes; but the optimizer does not.

---

[1] Walker, W. Adjacent extreme point algorithms for the fixed charge problem. Technical Report No. 40. Ithaca, N. Y., Cornell University, College of Engineering, Department of Operations Research, Jan. 30, 1968. 23 p.

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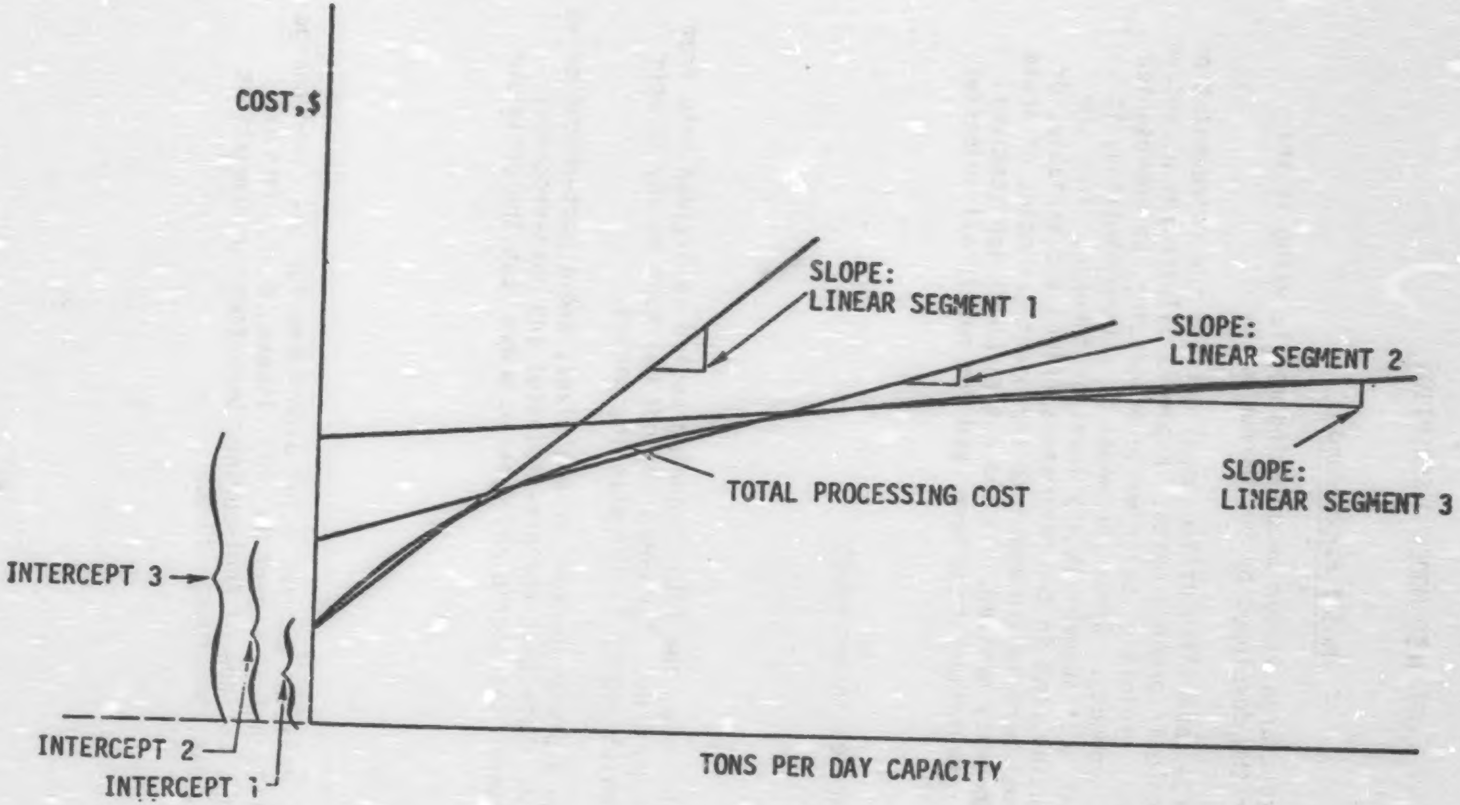
COST,$
SLOPE:
LINEAR SEGMENT 1
SLOPE:
LINEAR SEGMENT 2
SLOPE:
LINEAR SEGMENT 3
TOTAL PROCESSING COST
INTERCEPT 3
INTERCEPT 2
INTERCEPT 1
TONS PER DAY CAPACITY

Figure 1. Piecewise Linear Approximation of a Concave Function (Representing Economies of Scale)

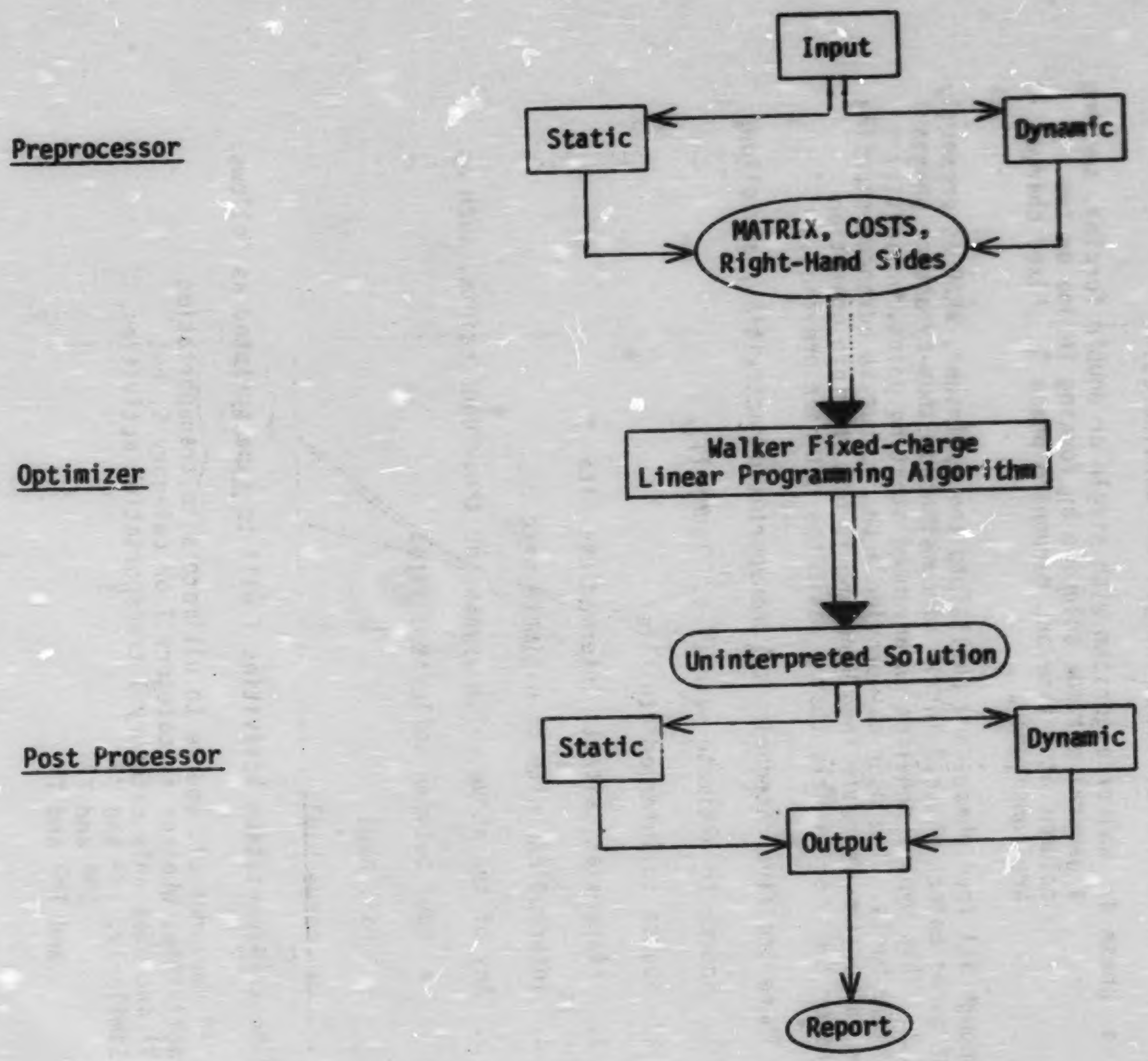
Preprocessor
Optimizer
Post Processor
Input
Static
Dynamic
MATRIX, COSTS, Right-Hand Sides
Walker Fixed-charge Linear Programming Algorithm
Uninterpreted Solution
Static
Dynamic
Output
Report

Figure 2. Model Organization

The optimizer operates in four phases:

- phase 1: linear programming phase 1, generating a feasible solution (i.e., no negative activity levels).
- phase 2: linear programming phase 2, generating an optimal solution without consideration of fixed charges.
- phase 3: Walker algorithm without forcing, generating a local optimum from adjacent extreme points which can improve the solution; fixed charges are considered.
- phase 4: Walker algorithm with single or double forcing, seeking a general optimum solution by forcing in one or two columns at a time and rerunning phase 3. Fixed charges are considered.

Although all four phases are built into the optimizer, WRAP as presently configured enters phase 3 in all circumstances, thus bypassing phases 1 and 2. This bypass requires an advanced starting point, or initial feasible basis. The user may provide a basis, but an advanced starting point algorithm is built into WRAP and is brought into operation whenever the user signals that a basis has not been provided.

There are five categories of transportation activities, as follows:

1. Source to ultimate site (i.e., landfill)
2. Source to intermediate site
3. Intermediate site to intermediate site
4. Intermediate site to ultimate site
5. Any of the above which bypass the truck constraints, such as:
    - haul between collocated sites
    - rail haul
    - barge haul.

The transportation activities T will be superscripted as follows:

T^{15} includes all source to ultimate site transportation activities whether in category 1 or category 5, but T^{1} includes only category 1 transportation activities.
Similarly, T^{25} and T^{2}
T^{35} and T^{3}
and T^{45} and T^{4}.

The T activities without the 5 superscript are used only in the truck constraints.

Equation Structure: Static Version

There are seven basic equations in the static version as follows:

Source Balance Equations

For each centroid source of waste generation there is a source balance equation,

$$\sum_k T^{15}_{ik} + \sum_j T^{25}_{ij} = G_i \qquad (1)$$

where

T^{15}_{ik} is transportation in thousand tons per year from source i to ultimate site k;
T^{25}_{ij} is transportation in thousand tons per year from source i to intermediate site j;

and

G_i is thousands of tons per year generated at site i.

This equation assures that all tonnage generated at a source is entered into transportation.

Intermediate and Ultimate Site Processing Constraints

For each intermediate site that is coded "limited" there is a processing constraint,

$$\sum_p \sum_l a_{jp} P_{jpl} \le K \qquad (2)$$

where

P_{jpl} is processing in thousand tons per year at intermediate site j, process p, linear segment l;
K is an arbitrarily large number (e.g., 1,000);

and

$a_{jp} = K/K_{jp}$ is the capacitation coefficient for intermediate site j, process p;

where

K_{jp} is the capacity in thousands of tons per year of process p at intermediate site j, assuming site j were totally devoted to process p.

This constraint is omitted for an unlimited intermediate site.

Similarly;

$$\sum_{p} \sum_{l} a_{kp} P_{kpl} \le K \qquad (3)$$

for ultimate site k.

Each ultimate site has one constraint. If the site is coded unlimited, a land constraint is entered:

$$\sum_{p} \sum_{l} d_{k} P_{kpl} \le K \qquad (3a)$$

where

$d_k = dK/L_k$ is the land requirement coefficient for ultimate site k;

d is the land requirement in acre-feet per thousand tons per year of sanitary landfill;

and

L_k is the available land at ultimate site k in acre-feet divided by the number of years in the planning period.

An effective density (defined as the weight of refuse divided by the volume of refuse plus cover, in place in a landfill) of 750 lbs/yd^3 is assumed.

If an ultimate site is coded limited, and if

(1) either there is only one process at the site, or

(2) if all processes have the same coefficient a_{kp}

then the tighter of equation 3 and equation 3a will be entered for the site.

If there are two or more processes at the site with differentiated coefficients a_{kp},
then a single equation will be formed by selecting for each process the larger coefficient from equation 3 or from equation 3a.

Intermediate Site Input Balance Equations

For each intermediate site there is an input balance equation,

$$\sum_{i} T^{25}_{ij} + \sum_{i}\sum_{p} T^{35}_{ipj} - \sum_{p}\sum_{l} P_{jpl} = 0 \qquad (4)$$

where

T^{35}_{ipj} is transportation in thousand tons per year from intermediate site i, process p, to intermediate site j.

The total transportation into each intermediate site equals the total processing at that site. The model is allowed to choose which process and which linear segment to use for the site, based on cost-minimization.

Ultimate Site Input Balance Equations

For each ultimate site there is an input balance equation,

$$\sum_{i} T^{15}_{ik} + \sum_{j}\sum_{p} c_p T^{45}_{jpk} - \sum_{p}\sum_{l} P_{kpl} = 0 \qquad (5)$$

where

T^{45}_{jpk} is transportation in thousand tons per year from intermediate site j, process p, to ultimate site k;

and

c_p is the density coefficient, or the ratio of the effective density of raw refuse in place in a landfill (750 lbs/yd³) to the effective density in place of the output of process p, assuming that that output were to be landfilled without further processing.

The total transportation into each ultimate site from all sources and intermediate site/processes, equals the total processing at that ultimate site, measured in equivalent (in volume) raw refuse tonnage.

Intermediate Facility Output Balance Equations

For each intermediate site/process there is an output balance equation,

$$\sum_k T^{45}_{jpk} + \sum_i T^{35}_{jpi} - b_p \sum_l P_{jpl} = 0 \qquad (6)$$

where

b_p is the output coefficient for process p, or the tons of non-saleable output per ton input;

and

T^{35}_{jpi} is the transportation in thousand tons per year from intermediate site j, process p, to intermediate site i.

The total transportation from each intermediate site/process to all intermediate and ultimate sites equals the total non-saleable output from processing at the intermediate site/process.

Truck Constraints

For each specified site or group of (up to three) collocated sites to be subjected to a truck constraint:

$$e_p\left[\sum T^1_s + \sum T^2_s\right] + e_t\left[\sum T^3_s + \sum T^4_s\right] \le M_s \qquad (7)$$

where

e_p is the reciprocal of tons per packer truck, as input

e_t is the reciprocal of tons per transfer vehicle, as input

$\sum T_s^c$ is the sum of transportation activities of category c, in thousands of tons, which either originate from or arrive at any of the specified sites of set s;

and

M_s is the maximum number of trucks, in thousands per year, permitted to service the set of sites s.

Cost Structure: Static Version

The cost for a transportation activity is the cost per ton transported, defined as the cost per ton-minute times the number of minutes. The cost per ton-minute is input separately for each source and for each process; the one-way transit time is input separately for each origin/destination pair, or generated by a subroutine from longitude and latitude coordinates and from average speed to be input. The number of minutes for a source origin is double the one-way transit time; the number of minutes for an intermediate site origin is double the one-way transit time plus a standard turn-around time, which is input.

Costs for processing activities are input as a capital intercept and slope and operating intercept and slope for each linear segment of each process, together representing an annual cost function per ton per year. The capital and operating slopes are added together in the static model, so that their division within a correct total is arbitrary. The same is true for capital and operating intercepts in the static model. Succeeding linear segments of the same process should show increasing intercepts and declining slopes.

A site-preparation cost, representing an amortized annual cost, is input separately for each site, and is added to the capital intercept of each linear segment of each process at that site.

A revenue per input ton is input separately for each site/process, and is subtracted from the operating slope of each segment of the site/process.

All other processing costs are input by process.

Each existing facility is identified as a separate process, e.g.:

process No. 913 Existing Lowell incinerator

process No. 914 Exisitng Salem incinerator.

This separate process identification will permit differentiated costing for existing facilities. An existing facility might have an intercept equal to the amortized annual cost of environmental upgrading, and a slope equal to the operating cost per ton. Sunk capital costs (and committed costs as well) should not be included in the cost function of an existing facility. A proper decision can be made by the model, as in any other decision analysis, only if decisions are related to the costs that they can affect. Both sunk costs and committed costs (i.e., costs irrevocably committed, but not yet expended) can only distort the decisions to be made by the model. They should properly be excluded.

Equation Structure: Dynamic Version

In the dynamic version, the processing activities P are not segmented, and are free of costs. Additional equations are added which require that processing activity in a period be less than or equal to capacity put into place during that period and prior periods as far back as its useful life or the start of the model, whichever is later. Costs of capital and full-capacity operation are charged against capital building activities K from the time of building to the end of the useful life or the end of the model, whichever is earlier, and these are broken into linear segments to represent economies of scale. An activity representing underutilization of capacity is provided, with a refund of operating cost slope, to permit the process to operate at less than full capacity in any period desired (cost-minimization will assure that no process operates at less than full capacity in all periods). This device of charging capital and full-capacity operating cost, and providing a refund of operating cost slope for less-than-full-capacity operation, permits the model to represent the concave cost functions in processing in a dynamic context, and also permits the model to overbuild capacity in an early period in order to allow for growth without incurring the additional intercept cost of a new capital-building activity. The model may of course elect not to overbuild capacity if that would lower the cost of the solution. The underutilization activity also permits the model to abandon capacity before the end of its useful life, if that will lower the system cost.

The dynamic version consists of nine basic equations as follows:

Source Balance Equations

For each centroid of waste generation in each model period there is a source balance equation,

$$\sum_k T^{15}_{ikt} + \sum_j T^{25}_{ijt} = G_{it} \qquad (8)$$

where

T^{15}_{ikt} is transportation in thousand tons per year from source i to ultimate site k in model period t;

T^{25}_{ijt} is transportation in thousand tons per year from source i to intermediate site j in model period t;

and

G_{it} is thousands of tons per year generated in centroid source i in model period t.

Intermediate and Ultimate Site Processing Constraints

For each limited intermediate site in each model period there is a processing constraint,

$$\sum_p a_{jp} P_{jpt} \leq K \qquad (9)$$

where

P_{jpt} is processing in thousand tons per year at intermediate site j, process p, in model period t.

Similarly;

$$\sum_p a_{kp} P_{kpt} \leq K \qquad (10)$$

for each ultimate limited site k. In the dynamic model, this constraint is omitted for both unlimited intermediate and unlimited ultimate sites, since a land constraint is provided in equation 17.

Intermediate Site Input Balance Equations

$$\sum_i T^{25}_{ijt} + \sum_i \sum_p T^{35}_{ipjt} - \sum_p P_{jpt} = 0 \qquad (11)$$

where

T^{35}_{ipjt} is transportation in thousand tons per year from site i, process p, to site j, in model period t.

Ultimate Site Input Balance Equations

For each ultimate site in each model period there is an input balance equation,

$$\sum_{i} T^{15}_{ikt} + \sum_{j} \sum_{p} c_p T^{45}_{jpkt} - \sum_{p} P_{kpt} = 0 \qquad (12)$$

where

T^{45}_{jpkt} is transportation in thousand tons per year from intermediate site j, process p, to ultimate site k, in model period t.

Intermediate Facility Output Balance Equations

For each intermediate site/process in each model period there is an output balance equation,

$$\sum_{k} T^{45}_{jpkt} + \sum_{i} T^{35}_{jpit} - b_p P_{jpt} = 0 \qquad (13)$$

where

T^{35}_{jpit} is the transportation in thousand tons per year from intermediate site j, process p, to intermediate site i, in model period t.

Truck Constraints

For each time period and each specified site or group of (up to three) collocated sites to be subjected to a truck constraint:

$$e_p \left[\sum T^{1}_{st} + \sum T^{2}_{st}\right] + e_t \left[\sum T^{3}_{st} + \sum T^{4}_{st}\right] \le M_{st} \qquad (14)$$

where

$\sum T^c_{st}$ is the sum of transportation activities of category c in model period t, in thousands of tons, which either originate from or arrive at any of the specified sites of set s;

and

M_{st} is the maximum number of trucks, in thousands per year, permitted to service the sites of set s in model period t.

Site/Process Capacity Balance Equations

For each intermediate site/process in each model period there is a site/process capacity balance equation,

$$P_{jpt} - \sum_{l} \sum_{m=s}^{t} K_{jplm} + S_{jpt} = 0 \qquad (15)$$

where

K_{jplt} is the capacity in thousand tons per year of process p at site j, linear segment l, put into place at the beginning of model period t;

S_{jpt} is the unused capacity, in thousand tons per year, of process p at site j in model period t;

and

s is the earliest model period in which capccity of process p put into place at site j would continue to be in operation in period t, or the first model period, whichever is later.

Similarly;

$$P_{kpt} - \sum_{l} \sum_{m=s}^{t} K_{kplm} + S_{kpt} = 0 \qquad (16)$$

for each ultimate site k, process p, model period t.

Land Constraints

For each ultimate site, there is a land constraint,

$$\sum_t d_t P_{kpt} \leq L_k \qquad (17)$$

where

L_k is the available land at ultimate site k in acre-feet;

p is the sanitary landfill process;

and

d_t is the land requirement in acre-feet per thousand tons per year of sanitary landfill, multipled by the number of years in model period t.

An effective density of 750 lbs/yd^3 is assumed.

This equation assures that the total landfill at site k over all model periods does not exceed the land available at that site.

Cost Structure: Dynamic Version

An annual discount rate and an annual inflation rate are input into the model (either of these may be bypassed by inputting rates of 1.000 in each case.)

Transportation cost is the sum of the annual discounted and inflated costs over the years included in the relevant model period for transporting one ton per year from origin to destination. The undiscounted and uninflated costs per ton-minute, and the distances, speeds, and times are obtained as in the static version.

Processing costs are input by process in cost sets. Each cost set will contain an annual operating cost function of tons per year, defined as an intercept and a slope, and an annual amortized capital cost function of tons per year, defined as an intercept and a slope, for each linear segment in the process. There is one cost set for each process for each period in which its capacity may be built.

The amortized capital costs should represent the dollar outflow per year to pay back the capital over the useful life of the process, and to pay interest at an appropriate rate (e.g., 7% for municipal projects and 10% for private projects), on the unamortized balance. The interest rate for amortization need not be related to the overall discount rate of the model. For amortization purposes, the actual useful life, and not the remaining time in the model, is relevant. Both capital and operating costs should be defined in dollars of the first year of the model, since they are inflated from that point.

The annual amortized cost per dollar of investment is:

$$\frac{i\ (1+i)^n}{(1+i)^n - 1}$$

where

i is the interest rate

and

n is the useful life.

A capital lead time is input for each process, representing the average investment lead time on facilities and equipment prior to first operational date, rounded to the nearest integer year.

Process costing (and capacities) assume that a process operates from the beginning of one period to the end of another. Thus the useful life is defined in whole model periods.

The process operating cost is discounted and inflated and summed over the years included from the time of first operation to the earlier of the end of its useful life or the end of the model. Capital costs are inflated only to the year (start of operation - capital lead time) and then discounted and summed over the same period as the operating costs. This differentiation represents the fact that capital costs are not subject to inflation once the commitment is made to pay them, whereas operating costs inflate throughout the useful life.

After appropriate inflation and discounting, operating and capital cost slopes are combined to obtain the slope of the linear segment, and operating and capital cost intercepts are combined to obtain the intercept of the linear segment. These costs are applied against capacity building activities K.

The S activities, representing the refund of operating cost for non-use of capacity, are costed by selection of the lowest operating cost slope relevant to the site/process, and inflating, discounting and summing over years of the relevant model period only.

Process cost sets are input by process, site preparation costs are input by site, and revenue per input ton is input by site/process. Before inflation, discounting, and summing, the site preparation cost is added to the capital cost intercept, and the revenue per input ton is subtracted from the operating cost slope. These adjustments relate to both K and S activities as appropriate.

If a process may be municipally financed at one site and privately financed at another, it should be input as two separate processes in order to allow cost differentiation.

It should be understood that the cost set for a period relates to facilities which begin operations at the beginning of that period. Thus, in model period t+1, a facility built in model period t would be costed with the period t cost set, with the one exception of the revenue per input ton, which relates to the period of operation. Thus, the revenue per input ton of period t+1, would be subtracted from the slope of period t operating costs to represent the undiscounted, uninflated net operating cost per year in period t+1.

CROW-FLY Program

There are three CROW-FLY options:

0: CROW-FLY will not be used

1: CROW-FLY will be used to generate up to ten origin-destination pairs; where input linkage or output linkage is missing (beyond ten the model will abort); CROW-FLY will be used to complete distance, speed, and time estimates as needed.

2: CROW-FLY will be used to generate all possible origin-destination pairs within a maximum radius, and beyond that limit where needed to complete input or output linkage; CROW-FLY will be used to complete distance, speed, and time estimates as needed.

The CROW-FLY Program, operating from coordinates in longitude and latitude, generates origin-destination pairs, measures distances, finds the shortest input linkage for a site, finds the shortest output linkage for a site, and applies a standard speed, as appropriate. CROW-FLY outputs can be available as a punched deck suitable for input as transportation activities, or alternatively can be input directly into the master program as transportation activities. A standard speed is input into the model as well as a maximum radius. The standard speed is used for all generated origin-destination pairs, and for any other pairs where required to generate one-way transit time in minutes. In CROW-FLY option 2, the maximum radius is used as a criterion to select generated pairs. All pairs less than the maximum radius will be selected, plus the shortest pair greater than the maximum radius where input or output linkage would otherwise be incomplete. CROW-FLY distances are straight-line flat-earth distances in nautical miles, but are translated into statute miles before being output to the CROW-FLY deck or to the master program. A standard factor of nautical miles per minute of longitude at approximately the center of the region is entered as input and used to translate longitude differences into nautical miles.

If CROW-FLY option 1 or 2 is selected, all sources, intermediate sites, and ultimate sites must be provided with coordinates in longitude and latitude in degrees, minutes, and 10ths of minutes.

Processing Levels

Four processing levels are provided in the model:

A. Transfer Station
  Input linkage from sources and level A
  Output linkage to levels A, B, and D

B. Primary Processing
  Input linkage from sources and level A
  Output linkage to levels C and D

C. Secondary Processing
  Input linkage from levels B and C
  Output linkage to levels C and D

D. Landfill
  Input linkage from sources and levels A, B, and C
  No output linkage

Levels A, B, and C are intermediate site levels and level D is an ultimate site level. The A-to-A linkage permits a packer-to-van transfer to be linked to a truck-to-rail or truck-to-barge transfer.

The C-to-C linkage permits ficticious processes to be established to generate differentiated revenues for different types of residues to be processed in the same secondary processing plant.

Fictitious B-level or C-level processes can be used to represent differentiated landfill costs (e.g., one process for balefill and another for standard sanitary landfill). If this is used, separate ficticious sites must be identified for balefill and standard landfill at the same real site (collocated) in order to achieve separate input balance, and then a D-level site and a costless D-level process can be driven by the two or more B or C-level site/processes to generate a proper land impact. A Category 5 transportation activity (which bypasses the truck constraint) with negative minutes will translate to a zero cost transportation activity. An output of 100% should be used for the B and C-level landfill processes, with the output densities of the processes preceding D-level being used to control the land impact at D-level. If differentiated land impact without differentiated cost is desired, the use of ficticious B or C-level activities is not necessary since that can be accomplished through the output densities of the processes preceding landfill.

Source Designation

Sources should be numbered from 100 to 499, and need not be consecutive.

Site Designation

The model provides a separate input balance and a separate site processing constraint for each separate site identification number. The user should use the same site number for collocated processes unless (1) there is a need to differentiate input, or (2) there is a need to differentiate land use. The use of the same site number permits the model to select the process in the course of its search for a minimum cost solution. It also reduces the required number of linkages. The need to differentiate input requires the designation of separate site numbers for collocated primary processing (B-level) and secondary processing (C-level) since the former processes raw refuse and the latter processes residue. The need to differentiate land use requires the designation of separate site numbers for D-level processing collocated with any other level.

A and B-level processes at the same site can be treated together and can be assigned the same site number. A and B-level sites should be numbered from 500 to 599, and need not be consecutive.

C-level processes should not be designated at the same sites where A, B, or D-level processes are designated. Separate C-level site numbers should be designated for C-level processes. These should be numbered from 600 to 699, and need not be consecutive.

D-level processes should not be designated at the same sites where A, B, or C-level processes are designated. Separate D-level site numbers should be designated and numbered from 700 to 799, the numbers need not be consecutive.

Process Designation

Processes should be numbered from 800 to 999, and need not be consecutive.

Transportation Specification

Transportation links are from source to site or from site/process to site.

If a zero transportation cost is desired, as between two collocated sites, (for example, primary and secondary processing at the same site) an input of -0.1 minutes (or any other negative quantity) will be translated by the model into a zero cost for the transportation activity. No turnaround time will be added in this case.

An input of zero or blank minutes will be read as a blank in CROW-FLY option 0 or 1, and as a zero in CROW-FLY option 2. Hence, if zero minutes are desired in CROW-FLY option 0 or 1 (which will add the standard turn-around time for a site origin) input a 1 in the last minutes place; this will be read as 0.1 minutes, and permit the program to continue. If this is too large, the decimal may be specified in the minutes field of the transportation card, and a very small (but positive number of minutes specified for the activity.

Where only one-way distance is provided, speed will be the standard speed provided as input, if CROW-FLY option 1 or 2 is selected; in CROW-FLY option 0, the run will abort.

Where none of the entries is provided, CROW-FLY will be used for distance, and standard speed will be used, if CROW-FLY option 1 or 2 is selected; in CROW-FLY option 0, the run will abort.

Where one-way minutes is provided, it will be used whether or not it is consistent with distance and speed inputs.

The set of transportation activities will be checked to verify that each source and site/process has output linkage, and that each site has input linkage. If linkage is missing, the shortest possible link will be generated through CROW-FLY and entered into the Transportation Activity File, if CROW-FLY option 1 or 2 is selected (up to 10 in option 1; unlimited in option 2); in CROW-FLY option 0, the run will abort.

If CROW-FLY is to be used only for the standard speed, it will still be necessary to provide longitudes and latitudes for each source and site. For this case, these may be input identically as 1 (or any positive number).

Sizing the Model

Dummy Row and Column

An additional row and column have been added to the matrix as follows:

Dummy Row: Capacitation, N.E.C. (Not Elsewhere Classified)

The sum of all processing activities which:

a. are at unlimited intermediate sites, and

b. have no output

are less than or equal to a very large number. This equation insures that there will be no activities other than slacks, which have only a single coefficient. The presence of such activities has led to cases of non-invertible bases in phase 1. This row is the last row in the static model, and precedes the site-process capacity balance equations in the dynamic model. (Phase 1 is now bypassed.)

Dummy Column: Column Z

An additional column with a minus one in each inequality (that is, each site capacitation, land constraint, or truck constraint, and in the capacitation n.e.c.) has been added for use in the automatic advanced starting point algorithm. This column relieves each constraint by one unit, and bears a variable cost of $1,000, so it will be easily driven out of the solution in phase 3 if there is a feasible solution.

Whether column Z is required for an advanced starting point or not, the program goes to phase 3 (linear programming with consideration of fixed costs for adjacent extreme points only).

Sizing the Static Model

Rows and Row Order

There will be one source balance equation for each source, sorted in order of source number. This will be the first set of equations.

There will be one site processing constraint for each limited intermediate site, and one site processing constraint for each ultimate site, sorted in order of site number. This will be the second set of equations.

There will be one input balance equation for each separate site, sorted by site number. This will be the third set of equations.

There will be one output balance equation for each separate site-process with positive output. This will be the fourth set of equations. Within the set, the equations will be sorted by process within site.

There will be a number of truck constraints as specified by the user, and in the order specified by the user. This will be the fifth set of equations.

There will be one capacitation, n.e.c., which will be the last equation.

Columns and Column Order

There will be a column for each separate transportation activity T. This will be the first set of columns, and will be sorted as follows:

Major: category number (category 1-5)
Next: origin
  Source
    Source number
  Site
    Site number
Next: origin process by process number
Next: destination by site number.

There will be a column for each processing activity P, representing each separate site, process, and linear segment. This will be the second set of columns and will be sorted by segment within process within site.

There will be one column Z, following the processing activities.

There will be a number of slacks equal to the number of inequalities, and a number of artificials equal to the number of rows minus the number of slacks (i.e., the number of equations). These will be ordered slacks, and then artificials; within each set, the columns will be ordered by the row number to which they correspond.

Sizing the Dynamic Model

Rows and Row Order

The static rows and row order exist in the dynamic model as well, except:

1. a site processing constraint exists for an ultimate site only if it is coded limited. (There is a separate land constraint which cuts across model periods).

2. The set of static rows as modified is repeated in each model period. The sort is:

   major: model period
   minor: same sort as the static model.

There is one capacitation, n.e.c., which follows the repeated static rows.

There is a site-process capacity balance equation for each combination of site, process, and model period which is indicated as available in the input. The rows are sorted by model period within process within site. This set of equations follows the capacitation, n.e.c.

There is one land equation for each ultimate site, sorted by site. This is the last set of equations.

Columns and Column Order

The static transportation and processing columns exist in the dynamic model, except:

1. the processing columns are site-process only (no differentiation by linear segment).

2. the set is repeated in each model period.

The static columns are sorted:

major: model period
minor: same sort as the static columns.

The capacity-building activities (K) follow the repeated static columns. There is one K activity for each site, process, model period, and linear segment in which the process is indicated by the input as available for capacity-building in the model period.

The K activities are sorted by linear segment, within process, within site, within model period.

There is one underutilization (S) activity for each site, process, and model period in which a corresponding P activity exists. The S activities follow the K activities, and are sorted by process, within site, within model period.

There is one column Z which follows the S activities.

There are slacks and artificials following Column Z defined and sorted as in the static case.

The number of columns before expansion is the number not including slacks and artificials.

The number of columns after expansion is the number including slacks and artificials.

The WRAP object program currently available from the EPA will handle a problem up to 90 rows by 360 columns (before expansion).

Advanced Starting Point (or Basis)

An advanced starting point may be provided by the users (and that fact must be indicated on the control card). If none is provided, an advanced starting point will be selected by a subroutine. In either case, the advanced starting point will be tested for feasibility. If it is feasible (i.e., provides a solution to the system of equations with no negative activity levels) the model will go to phase 3. If the advanced starting point generates one or more negative activity levels, the column with the largest negative activity level will be replaced by column Z (which relieves all constraints) and the advanced starting point will be tested for feasibility. If there is still a negative activity level, the program will abort. If there are no negative activity levels, phase 3 will be entered.

The advanced starting point must specify a number of columns equal to the number of rows. The columns are specified by sequential column number.

Advanced Starting Point Subroutine

Static Case

For all inequalities, the slack is selected. These are sequential column numbers from the number of columns before expansion plus one through the number of columns before expansion plus the number of inequalities.

For each source balance equation, one type 2 or type 1 transportation activity is selected in which the source is origin; type 2 takes precedence over type 1; within each, the first available transportation activity is selected.

For each input balance equation, one processing activity at the site is selected. First precedence is given to minimum percent output by weight. For equal percent outputs by weight, the lowest process number and linear segment number at the site is selected.

For each output balance equation, one type 5 or type 3 transportation activity in which the site-process is origin is selected. Type 5 takes precedence over type 3; within each, the first available activity is selected.

Dynamic Case

For the static repeated equations the static rules for activity selection are followed except:

For input balance equations, a processing activity selected for a site in an earlier period is given first precedence for the next succeeding period for the same site if it is still available.

For site/process capacity balance equations, the K activity matching in site, process, and period, first available linear segment, is selected. If no matching K activity exists, the corresponding S activity is selected.

CHAPTER 3

SPECIFYING THE MODEL INPUT

Summary of Input Cards

There are fourteen input card types as follows:

Card	ID Code	Number Required
Control	CONTRL	one
Dynamic Control	CNTR2	one for dynamic run only
Title	TITLE	one
CROW-FLY	CRWFLY	one if CROW-FLY option (control card, col. 23) is 1 or 2
Source	SOURCE	At least one (one per source)
Site	SITE	At least one (one per site)
Process Header #1	PRC1	At least one (one per process)
Process Header #2	PRC2	At least one (one per process)
Process Input Links	LNKI	At least one (one or two per process)
Process Output Links	LNKO	One or two per process with output
Process Cost	PRCOST	One per process per linear segment per model period
Site Process	SIPROC	One for each process at each site
Transportation	TRANS	One per user-provided transportation activity
Truck	TRUCK	one per truck constraint

The model input is here described in detail for each data field of each of the different types of data input cards with annotations following the description. A complete input listing for one static run (Northeast Massachusetts Run B-2) and for one dynamic run (St. Louis G) is provided in Chapter 5.

Each card starts with an identification, or ID code.

Control Card

One always required.

	Columns
ID Code: "CONTRL"	1-6
Mode of Execution	9

1 = static
2 = dynamic

Columns

Last Phase of Execution (3 or 4)

11

It is suggested that the user proceed with caution in using phase 4 beyond a size of 70 rows by 200 columns. The running time tends to increase enormously.

Forcing for Phase 4 Only

13

1 = single
2 = double

Single forcing is suggested for all but very small problems. In single forcing, each column outside the basis is forced in and a phase 3 (adjacent extreme point optimization) is performed. If the solution is improved, the column is kept; otherwise the model reverts to the previous best solution.

In double forcing, each column outside the basis is forced in, and while it is held in, each other column outside the basis is forced in and a phase 3 is performed. While single forcing may miss the optimum solution, double-forcing runs can be costly. A viable alternative is a technique known as configuration forcing, in which the model is made to look at a different solution structure, either by making an option unavailable, or by raising the cost of an option, or by a controlled advanced starting point. Several single forcing runs, using configuration forcing, are much less expensive than one double forcing run.

Output Printing Options

15

1 = complete [Rows (right-hand sides); columns (costs); matrix; intermediate and final output]
2 = I-O summary and final output (number of rows and columns; number of non-zero coefficients; last-phase output only
3 = I-O summary and all output (intermediate-phase output is provided).

These refer to Walker algorithm outputs only. WRAP inputs and post processor outputs are always provided.

Steepest Descent Request

17

1 = No
2 = Yes

Without steepest descent, the first column which is discovered to improve the solution is selected for introduction. With steepest descent, all columns outside of the basis are evaluated, and that column which makes the greatest improvement in the solution is introduced.

2 is recommended for all applications.

	Columns
Starting Basis Available	19

1 = No
2 = Yes

An advanced starting point can be used as a primary control in configuration forcing. If 1 (no) is selected, the advanced starting point subroutine will generate a starting basis. If 2 is selected, a starting basis must be provided at the end of the input.

Punch Final Basis	21

1 = No
2 = Yes

An entry of 2 will generate the model solution in the form of a starting basis. This is useful if and only if a succeeding run retains the same row and column structure, which means that costs can be freely changed and the generated starting basis used. Right-hand sides and flow coefficients can also be changed, but with a risk of the basis becoming infeasible, which would cause the run to abort.

CROW-FLY Option	23

0 = No
1 = Limited
2 = Maximum radius

Option 0

The program will abort if (1) there is any site without input linkage (i.e., through transportation activities input on transportation cards; or (2) any source, or site-process with positive percent output by weight, is without output linkage. Each transportation activity must have positive minutes, or otherwise the run will abort. If zero minutes is desired, specify a very small value in the minutes field.

Option 1

Any missing linkage will be provided with the shortest distance link, for up to ten separate omissions, (i.e., transportation activities will be generated). Beyond ten omissions, the program will abort. Speed and/or distance will be provided without limit for identified transportation activities which lack such measures. A zero or a blank will be read as a blank for minutes, distance, or speed. If zero minutes is to be stipulated, a very small positive value should be inserted in the minutes field; although equal longitude and latitude will generate zero minutes in any case.

Option 2

All legal links will be defined up to a maximum radius, plus the shortest legal link if the maximus radius does not complete linkage.

If option 1 or 2 is selected, longitude and latitude must be provided for all sources and sites, but these may be dummied in (e.g., all 1's) if only speed is to be provided by CROW-FLY.

In CROW-FLY Options 1 and 2, the following priority system exists:

1. A transportation activity provided by the user (on a transportation card) for a link will prevent Crow-Fly from generating a transportation activity for that link.

2. Any of speed, distance, or time estimates provided by the user (on a transportation card) for a link will prevent CROW-FLY from generating corresponding estimates for that link. If distance only is provided by the user, CROW-FLY will use the standard speed and the user-provided distance to estimate one-way time in minutes; if speed only is provided by the user, CROW-FLY will generate distance, and then use that and the user-provided speed to estimate one-way minutes. If a transportation card is used to provide a link, but all of the distance, speed, and time fields are left blank, CROW-FLY will estimate distance, and use the standard speed to estimate one-way time in minutes.

3. If one-way minutes are provided by the user on a transportation card, that will be used by the model whether or not distance and speed are also provided. If all three are provided, the consistency will not be checked.

Columns

Punch Transportation Results 25

0 = No; continue
1 = Yes and stop
2 = Yes and continue

Transportation activities generated by CROW-FLY may be punched out, inspected, and reinserted as a provided transportation file. These cards may be obtained with a program stop (select 1) or with a continuation (select 2). The cards will be formatted as Transportation Cards.

Punch Out Prepared Algorithm Input 27

0 = No; continue
1 = Yes; stop
2 = Yes; continue

The preprocessor results may be punched out as a matrix, costs, and right-hand sides, in a form suitable for input into a separate Walker Algorithm. This algorithm is available as proprietary software known as FCSS from Compuvisor, Inc. This output cannot be used with the WRAP model.

Truck Constraint Option 29

1 = No
2 = Yes

If 1 is selected, columns 51 and 52 should be left blank. If 2 is selected, the number of truck constraints (i.e., number of Truck Cards) should be provided in columns 51 and 52.

Number of Modeling Periods 31

1 if static
2-4 if dynamic

Number of Sources 33-35

This must be equal to the number of source cards submitted.

Number of Intermediate and Ultimate Sites 38-39

This must be equal to the number of site cards submitted.

Columns

Number of Processes 40-41

This must be equal to the number of Process Header #1 and #2 cards submitted.

Number of Site-Processes 43-45

This must be equal to the number of site process cards submitted.

Number of Transportation Activities 47-49

This must be equal to the number of transportation cards submitted.

Number of Truck Constraints 51-52

This must be equal to the number of truck cards submitted.

There should be a zero here if there is a 1 in column 29.

Standard Turn-Around Time 55-58

in minutes decimal: 58.59
added to 2-way minutes for transportation originating at a site.

This turnaround time represents the time to load a transfer van at a transfer station, the time to unload it at the destination, and the maneuver time at both locations. If it is necessary to differentiate turnaround time from site to site, enter the least turnaround time as the standard turnaround time in columns 55-58, and then add additional time as needed for a site to the one-way minutes field on each of the transportation cards originating at that site. The amount to be added should be one-half the difference between the site turnaround time and the standard turnaround time, since the one-way minutes entry is later doubled in estimating haul cost.

No turnaround time is included for packer haul (i.e., haul originating at a source) since that would merely generate a constant cost in the model, independent of anything the model did. In a sense, the packer unloading time is generated by the loading of the packer, and not controlled by the model. The model charges itself for incremental time incurred on the packer trucks as a function of the model's choice of offload points for the packers.

		Columns
Number of Years in Total Planning Period		60-61
Number of Years in Each Model Period		
Any integer number	1st period	63-64
	2nd period	66-67
	3rd period	69-70
	4th period	72-73

Fill in 1st period only for a static run; leave blank for any period which does not apply.

Capacity of Packer Vehicles	75-76

Average tons per truck; used for truck constraint coefficients.

Capacity of Transfer Vehicles	78-79

Average tons per truck; used for truck constraint coefficients.

Dynamic Control Card

One required for Dynamic Run only.

	Columns
ID Code: "CNTR2"	1-5
Inflation Rate (annual)	7-10 decimal: 7.8

The rate should be greater than or equal to 1.0. A rate of 1.0 avoids the use of an inflator.

Discount Rate (annual)	12-15 decimal: 12.13

The rate should be less than or equal to 1.0; for a discount rate of i,

$$\frac{1}{1+i}$$

should be entered as the discount rate. A rate of 1.0 avoids discounting.

In a dynamic run, the inflation rate and discount rate are used to inflate and discount all costs and revenues, except capital costs between the years in which they occur and the first year of the model.

Amortized capital costs are inflated only to the year in which the capacity first becomes available minus the number of years in the capital lead time (provided on the process header #1, column 74). These costs are however discounted from the years in which they occur to the first year of the model.

The amortized capital costs should represent the dollar outflows per year to pay back the capital over the useful life of the process, and to pay interest at an appropriate rate (e.g., 7% for municipal projects and 10% for private projects) on the unamortized balance. The interest rate for amortization need not be related to the overall discount rate which is entered on the Dynamic Control Card. It is the dollar outflow per year, defined as above, and established through a project interest rate, that is inflated and discounted, using the model discount rate.

Title Card

One always required.

	Columns
ID Code: "TITLE"	1-5
Title Information	7-80

CROW-FLY Card

One required only if CROW-FLY option (Control Card, Column 23) is 1 or 2.

Columns

ID Code: "CRWFLY" 1-6

Maximum Radius (miles) 9-11

(From 001 to 700)
Criterion for selection in CROW-FLY Option 2.

Nautical Miles Per Minute of Longitude 13-16
decimal: 13.14

This should be estimated for the center of the region. It is 1.0 at the equator, and less elsewhere.

Standard Speed 18-19

In integer miles per hour, averaged for the region over all roads and truck types. This speed is used for a link where neither one-way minutes nor speed has been provided by the user for that link; and where the CROW-FLY option is 1 or 2.

Source Card

One card for each source. The number of source cards supplied must equal the Number of Sources control variable (control card, columns 33-35). All source cards must be submitted in one group, but may be in any order within the group.

At least one source card is required.

		Columns
ID Code: "SOURCE"		1-6
Source Identification Number		7-9

A three digit number from 100 to 499.
Numbers need not be consecutive.

Source Name		10-29
Source Longitude		
Degrees		30-31
Minutes		32-34
	decimal:	33.34
Source Latitude		
Degrees		35-36
Minutes		37-39
	decimal:	38.39

Longitude and latitude need not be entered if the CROW-FLY option is 0 (control card, column 23). If Crow-Fly option is 1 or 2, longitude and latitude must be entered. If CROW-FLY is to be used only for standard speed, any arbitrary positive numbers may be filled in. If necessary, a constant should be added to or subtracted from all longitudes or latitudes to make all of the entries for the region fit within the available field. For example, in Los Angeles, the user might subtract 100 degrees from all longitudes.

Source Tons in Thousands of Tons Per Year		
1st period		40-44
	decimal:	43.44
2nd period		45-49
	decimal:	48.49

		Columns
3rd period		50-54
	decimal:	53.54
4th period		55-59
	decimal:	58.59

For the static mode, use columns 40-44 only. Leave blank fields that do not apply (i.e., 3rd and 4th periods for a 2-period run). This should be consistent with number of periods in column 31 of the control card.

Source Haul Cost per Ton-Minute

1st period		60-64
	decimal:	(59).60
2nd period		65-69
	decimal:	(64).65
3rd period		70-74
	decimal:	(69).70
4th period		75-79
	decimal:	(74).75

This should be the cost per packer truck per minute of operation divided by an average load in tons.

Fill in only those fields appropriate to the run. This should be consistent with the number of periods in column 31 of the control card.

Site Card

One card for each site. The number of site cards supplied must equal the Number of Sites control variable (control card, columns 38-39). All site cards must be submitted in one group but may be in any order within the group.

	Columns
ID Code: "SITE"	1-4
Site Identification Number	6-8

This is a primary control in the design of an application.

500-599 for A level (transportation) and B level (primary processing)
600-699 for C level (secondary processing)
700-799 for D level (landfill)

Note: The model provides a separate input balance and a separate site processing constraint for each separate site identification number. The user should use the same site number for collocated processes unless (1) there is a need to differentiate input, or (2) there is a need to differentiate land use. The use of the same site number permits the model to select the process in the course of its search for a minimum cost solution. It also reduces the required number of linkages. The need to differentiate input requires the designation of separate site numbers for collocated primary processing (B-level) and secondary processing (C-level), since the former processes raw refuse and the latter processes residue. The need to differentiate land use requires the designation of separate site numbers for D-level processing collocated with any other level.

Identical second and third digits can be used as a mnemonic for cases of A/B-level and C-level collocation. This number assignment has no model control function. Collocation is accomplished by:

1. providing a category 5 transportation activity with zero cost (negative quantity in the minutes field of that TRANS card); and
2. if there is a truck constraint, listing the collocated site numbers on the TRUCK card.

Site Name	10-29

Columns

Site Type 32

1 = unlimited - there is no tonnage constraint, but there may still be a truck constraint.
2 = limited - tonnage capacities should be provided on the SITE-PROCESS card.

Site Longitude

Degrees 34-35

Minutes 36-38

decimal: 37.38

Site Latitude

Degrees 40-41
Minutes 42-44
decimal: 43.44

All of the comments on Source longitude and latitude apply here exactly.

Number of Processes Proposed at this Site 46

Site Preparation Cost 48-53
decimal: 51.52

In thousands of dollars per year, amortized, representing those costs that pertain to the site, rather than the process. This cost includes building access to the site, grading, blasting, etc., as necessary, to prepare the site to receive the processes proposed for it. If the user wishes, he may include the cost of the land also.

This cost is added to the capital intercept cost for each segment of each process at the site. A negative site preparation cost was used in the Massachusetts Exercise Series to represent the annual amortized value of an EPA grant at site 607, Lowell secondary processing, which could be retained in fact only if the particular process (Bureau of Mines incinerator residue process, process number 906) were retained in Lowell. This device could not have been used if there were a second process at the site. If that were the case, it would have been necessary to identify secondary processing at Lowell as a separate process, and to represent the value of the EPA grant as a reduced capital intercept on the process cost card.

The formula

$$C_a = \frac{i\,(1+i)^n}{(1+i)^n - 1}$$

where

C_a is the annual payback factor

i is the interest rate per year

and

n is the useful life in years

should be used to determine all amortized costs. The interest rate and useful life for the site preparation cost should be consistent with those of the capital intercept and slope of the process cost card.

If for any reason it is not possible to apply the same site preparation cost to all processes at a site, it will be necessary to identify separate process numbers for that site, and apply the appropriate site preparation cost to the capital intercept cost on the process card.

Columns
55-60
decimal: 60.(61)

Land Available in acre-feet

Enter only for a D-level (i.e., sanitary landfill) site.

The Process File

There are five different process cards, Process Header #1 (PRC1), Process Header #2 (PRC2), Process Input Links Card (LNKI), Process Output Links Card (LNKO), and Process Cost Card(PRCOST). It is essential that these cards should be entered into the model in the following order for each process:

PRC1,
PRC2,
LNKI,
LNKO,
PRCOST
  by model period
    by linear segment within model period.

The process identification number is entered into columns 78-80 of each card in the process file except the PRC1 card, in which that number is entered in columns 9-11.

Processes need not be input in order of process identification number.

A single process may be offered at only one site if the process existence code (Process Header #1, column 38) is 1 (existing) but may be offered at many sites if the process existence code is 2 (new). If a process is offered at more than one site, the user must make certain that all of the information provided for the process applies at all sites at which it is offered. If any information must be differentiated, it will be necessary to designate different process numbers, and to set up different processes in the file.

The assignment of processes to sites is made on the site process card.

Process Header #1

One per process (the total number must be equal to the number of processes on the control card, columns 40 and 41.)

Columns

ID Code: "PRC1" 1-4

Process Identification Number 9-11

A different number from 800 to 999, should be assigned whenever it is necessary to differentiate any entry on any card in the process file.

Process Name 13-32

Process Level Code 36

A = transfer
B = primary processing
C = secondary processing
D = landfill

Process Existence Code 38

1 - existing
2 = new

An existing process can be assigned at only one site (and that is edit checked).

Percent (non-saleable) Output by Weight 39-43
decimal: 41.42

Should be left blank if there is no non-saleable output.

Output Density 45-48
in pounds per cubic yard decimal: 48.(49)

This is the effective density of the non-saleable output of this process if put in a quality landfill, assuming that no further processing intervenes. Effective density is the weight of the waste in place divided by the volume of the waste plus cover (if applicable). The output density must be provided if percent output by weight is positive, and should be left blank if percent output be weight is zero. The output density controls the cost and land impact of sanitary landfill. For example, an output density of 1500 pounds per cubic yard, twice that of raw-refuse landfill, would generate only half as much processing cost and land use per ton as would raw refuse.

The effective density of raw refuse landfill is built into the model at 750 pounds per cubic yard.

A transfer station process should use an output density of 750.

Haul Cost per Ton-Minute

		Columns
1st period		50-54
	decimal:	(49).50
2nd period		56-60
	decimal:	(55).56
3rd period		62-66
	decimal:	(61).62
4th period		68-72
	decimal:	(67).68

This cost is the cost of a suitable truck per minute divided by the number of tons in an average load.

This should be left blank if the percent non-saleable output by weight is zero. With positive percent output by weight, data for a number of periods should be entered consistent with the number of periods in column 31 of the control card.

Capital Lead Time (in integer years) 74

The average lead time between commitment of capital and initial operating capability of the plant.

This field should be left blank in a static application.

In a dynamic application, the capital lead time controls the end of inflation for capital costs.

Process Header #2

One is required for each process.

	Columns
ID Code: "PRC2"	1-4

Process Availability to be Built

Period 1	7
Period 2	9
Period 3	11
Period 4	13

1 = not available for building in that period
2 = available for building in that period.

In static applications, enter a 2 in column 7 and leave others blank. In a dynamic application, fill in a number of fields consistent with the number of periods in column 31 of the control card.

A process may not be available in an earlier period because it is not yet developed; a process may not be available in a later period because of tightening environmental constraints.

Final Period of Availability of a Facility Built in:

Period 1	15
Period 2	17
Period 3	19
Period 4	21

For each model period enter a number 1 through 4 as appropriate to indicate the last model period during which the process would be available if the facility were constructed during this period. For example, if each model period is five years and this type of process facility normally has a ten year life, then if the facility were constructed in period 1, it would be available through period 2 (these two periods together being ten years) and you would put a "2" in column 15. The number entered cannot be less than the period. Enter data for a number of periods equal to the number of model periods entered in column 31 of the control card.

For static applications, enter a 1 in column 15, and leave the others blank.

	Columns
Number of Segments	31

Enter 1, 2, or 3 to indicate the number of linear segments which will be used to represent the cost functions for this process.

Process Identification Number	78-80

Process Input Links Card

At least one process input links card is required per process. This card identifies as "links" those processes the outputs of which may be input into the subject process. The first link field is used to indicate whether the subject process can receive directly from sources. There must be at least one positive link for each process (i.e., if the process cannot receive from source, it must receive outputs from at least one other process).

Up to 18 links may be supplied per card. Thirty-five (35) is the maximum total links possible. A zero or blank must be supplied in the link field following the last link. (If the last link is at the end of a card, a dummy link card with zero or blank in the first link field must follow.)

		Columns
ID Code: "LNKI"		1-4
Link 1	(1st link on 1st LNKI card is used to indicate if the process can receive directly from sources.) 1 = no source link 2 = source link (on 2nd LNKI card, the first link field is in columns 7-9).	9
Other Link Fields	Fill in process identification numbers of processes, the outputs of which may be input into the subject process. List in increasing order of process identification number.	11-13 15-17 19-21 23-25 27-29 31-33 35-37 39-41 43-45 47-49 51-53 55-57 59-61 63-65 67-69 71-73 75-77
Process Identification Number		78-80

Process Output Links Card

A process output links card is required if and only if Percent Non-Saleable Output by Weight on Process Header #1 is greater than zero. Otherwise omit. This card identifies as "links" those other processes which can receive the outputs of the subject process. Up to 18 links may be supplied per card. Thirty-six (36) is the maximum total number of links.

A zero or blank must be supplied in the link position following the last link supplied. (If the last link is at the end of a card a dummy output links card with a zero or blank in the first link position must follow.)

	Columns
ID Code: "LNKO"	1-4
1st Link Field	7-9
Other Link Fields Fill in process identification numbers of processes which may receive the non-saleable or residue outputs of the subject process, in increasing order of process identification number.	11-13 15-17 19-21 23-25 27-29 31-33 35-37 39-41 43-45 47-49 51-53 55-57 59-61 63-65 67-69 71-73 75-77
Process Identification Number	78-80

Process Cost Card

There must be one process card per linear segment per model period. For example, for 3 linear segments, 4 model periods, there must be 12 process cost cards. Do not submit cost cards for model periods in which the process is coded as non-available for building (PRC2, columns 7, 9, 11, and 13).

This card is the primary method for inputting cost data. A capital cost slope and intercept and operating cost slope and intercept are submitted on this card for the process wherever located. In addition, a site preparation cost, submitted on the SITE card, is added to each capital intercept of each process at the site. A third component of cost, revenue per input ton, is submitted on the SITE PROCESS Card (SIPROC). The revenue is subtracted from the operating cost slope for each segment of the site-process. Submitting the revenue by site process permits the revenue to be differentiated by site, representing more or less favorable location vis-a-vis markets.

In static applications, the differentiation between capital and operating costs is arbitrary, since they are merely added together to obtain a combined slope and a combined intercept.

One good way to prepare cost information is to perform all process cost analyses on log/log graph paper, thus obtaining a best fit curve in the form of one or more log-linear segments for cost versus scale. The cost estimate would then be transferred to straight graph paper on which from one to three linear segments can be fitted to the curve. Where capital and operating costs exhibit substantially different scale effects, capital and operating costs should be estimated independently. Where the slopes are similar, it is possible to estimate the total cost and the capital cost, and to treat the operating cost as a residual (that is, the difference between total and capital costs).

	Columns
ID Code: "PRCOST"	1-6
Model Period (1, 2, 3, or 4)	8
Segment Identifier (1, 2, or 3, segment 1 being leftmost on the graph)	9
Capital Slope (thousands of dollars per thousand tons)	11-19
decimal:	13.14

	Columns
Capital Intercept (thousands of dollars per year	21-29
decimal:	26.27
Operating Slope (thousands of dollars per thousand tons)	31-39
decimal:	33.34
Operating Intercept (thousands of dollars per year)	41-49
decimal:	46.47
Process Identification Number	78-80

All capital costs should be amortized annual costs using the following formula to estimate the payback factor:

$$C_a = \frac{i\,(1+i)^n}{(1+i)^n - 1}$$

where

C_a is capital payback factor

i is the interest rate per year

and

n is the number of years in the useful life.

The interest rate should be appropriate to the process, and need not be the same as the discount rate used for the model as a whole.

If the process can exist at one site under municipal financing, and another under private financing, two different process identification numbers should be assigned in order to differentiate the capital payback factor.

The process interest rates are used to establish annual amortized costs which in turn are discounted in a dynamic run using the model discount rate input on the dynamic card. There is no discounting in a static run.

Site Process Card

One is required for each process at each site.

	Columns
ID Code: "SIPROC"	1-6
Site Identification Number	8-10
Process Identification Number	12-14
Segments	18-19

Identify which segments of the process cost represent facility sizes which might be built at a particular site by the following:

01 = 1st only
02 = 2nd only
03 = 3rd only
12 = 1st and 2nd
23 = 2nd and 3rd
13 = all three of three.

Capacity (in thousands of tons per year)	21-24
decimal:	24.(25)

This is to be entered only for a site coded "limited" on the site card, column 32.

It is the maximum tonnage at the site assuming the subject process and only the subject process is selected at that site.

Revenue Per Input Ton

Net revenue (less cost of haul to market)

1st period	26-31
decimal:	28.29
2nd period	33-38
decimal:	35.36
3rd period	40-45
decimal:	42.43

	Columns
4th period	47-52
decimal:	49.50
Process Level (A, B, C, or D)	54

(Must be same as on PRC1, column 36)

Transportation Card

Each transportation card sets up a single transportation activity. Additional transportation activities may be established in CROW-FLY if CROW-FLY option 1 or 2 is selected. The number of transportation cards must equal the number entered on the control card, columns 47-49, representing the number of transportation activities provided by the user.

If the CROW-FLY option is 0 (column 23 of the control card), then transportation activities (i.e., transportation cards) must be provided sufficient so that each source, and each site-process with positive output, will have at least one outgoing transportation activity, and so that each site will have at least one incoming transportation activity. The input is edit-checked for linkage sufficiency in the above sense, and if the test fails, the run will abort.

If the CROW-FLY option is 1, up to ten transportation activities will be created to complete linkage, using a minimum distance criterion for selecting one activity for each case of incomplete linkage; but beyond that the run will abort.

If CROW-FLY 2 is selected, transportation activities will be generated for all legal linkage (the LNKI and LNKO data being the criteria of legality) up to a maximum radius provided on the CROW-FLY card. In cases of incomplete linkage (i.e., there is no linkage that can be made within the maximum radius), one additional transportation activity will be provided beyond the maximum radius criterion for each case of incomplete linkage. In CROW-FLY option 2, an activity provided by the user on a transportation card will supersede a generated activity.

Every transportation card must have entries for activity type, activity origin by ID number, and activity destination. If the CROW-FLY option is 0, activity origin process by number and one-way time in minutes must also be provided. In CROW-FLY option 1 or 2, one-way distance and speed in mph, if provided by the user, will be used to calculate one-way time in minutes, unless one-way time in minutes has also been provided by the user. One-way time in minutes will dominate if provided, and will not be checked for consistency with distance and speed if all three are provided.

In any CROW-FLY option, a negative quantity in the one-way time in minutes field will generate a zero cost transportation activity; i.e., even turnaround time will not be added.

In CROW-FLY 2, a zero entry or a blank in the one-way minutes field will be read as zero minutes. Turnaround time will be added if appropriate. In CRCW-FLY 0 and 1, a blank or a zero in the one-way time in minutes field will be read as a blank. In CROW-FLY 0, the run will abort if a blank is read in minutes; in CROW-FLY 1, the blank will lead to a measurement of the distance and speed as appropriate. The user should thus enter a very small positive quantity in the one-way time in minutes fields if he wishes a zero read in either CROW-FLY option 0 or 1. In this way, the turnaround time will be added. Note that only a negative quantity in the minutes field will avoid the addition of the turnaround time.

	Columns
Id Code: "TRANS"	1-5
Activity Type*	7
1 = source to ultimate site 2 = source to intermediate site 3 = intermediate to intermediate site 4 = intermediate to ultimate site 5 = any of the above that is to avoid any truck constraints placed on the origin and destination sites	
Activity Origin Site or Source ID Number*	9-11
Activity Origin Process ID Number+	13-15
If source origin, repeat source ID number	
Activity Destination Site ID Number*	17-19
One-way Time in Minutes+	24-28
	decimal: 27.28
One-way Distance in Miles	30-33
(statute miles)	decimal: 32.33
Speed in Miles Per Hour	35-37
	decimal: 36.37

---

*Required for any CROW-FLY option.
+Required for CROW-FLY option 0.

Truck Card

One card must be provided per truck constraint. The number of truck cards must be equal to the number indicated on the control card, columns 51-52.

	Columns
ID Code: "TRUCK"	1-5
Site Numbers (up to three)	7-9
The indicated sites are jointly subjected to a single truck constraint for all outgoing and incoming trucks, except for type 5 transportation activities.	11-13 15-17

Maximum Number Per Year (in thousands of trucks)

Fill in for a number of periods equal to the number of model periods (control card, column 31).

1st period		19-23
	decimal:	22.23
2nd period		25-29
	decimal:	28.29
3rd period		31-35
	decimal:	34.35
4th period		37-41
	decimal:	40.41

Advanced Starting Point (or Basis)

Enter a number of column index numbers equal to the number of equations. Enter 16 columns per card, using columns 2-4 7-9 12-14 ---- 77-79.

One source of an advanced starting basis would be the final basis (or optional card output) of a previous WRAP execution, obtained by entering 2 on the control card, column 21. This can be used only if the same row and column structure is maintained for both runs. This limitation permits costs to be modified freely. Right-hand sides and flow coefficients may also be modified with care to ensure that the basis does not become infeasible. If that were to happen, the run would abort.

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CODING FORM

AUTHOR
PROGRAM NAME
PROGRAM NUMBER
DATE
PAGE
OF

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

CARD CODE: JUMP CODE, EXECUTE MODE, LAST PHASE, TYPE OF FORMS, SNAP PRINT, STEEP DESCENT, BASIS IN, BASIS OUT, CAPACITY, TRANS OUT, MODEL OUT, TRUCKS IN, MODEL PERIODS, NUMBER OF SOURCES, NUMBER OF INTERMEDIATE, NUMBER OF ULTIMATE, NUMBER OF PROCESS, NUMBER OF SITE - PROCESS, NUMBER OF TRANSPORTATION ACTIVITIES, NUMBER OF TRUCK CARDS, STANDARD TURN AROUND TIME, TOTAL YEARS IN PLANNING, NUMBER OF YEARS EACH PERIOD, CAP OF TRUCKS, PACKER, TRANSFER

CONTRL

CARD CODE: ANNUAL INFLATION RATE, ANNUAL DISCOUNT RATE

CNTR2

CARD CODE: TITLE INFORMATION (TO COLUMN 80)

TITLE

CARD CODE: MAX. RADIUS MILES, RATE MILES/ MIN OF ROAD, STANDARD SPEED

CRWFLY

Note: 1. CONTRL, column 8, jump code: leave blank

2. CONTRL, columns 36-39, number of intermediate and ultimate sites: these may be entered seperately with number of intermediate sites in columns 36-37 and number of ultimate sites in columns 38-39; or they may be combined and entered into columns 38-39 as in the control card instructions.

CODING FORM

AUTHOR	PROGRAM NAME	PROGRAM NUMBER	DATE	PAGE OF

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

CARD CODE

LONGITUDE DEGREES

MINUTES AND TENTHS

LATITUDE DEGREES

MINUTES AND TENTHS

1 2 3 4 1 2 3 4

SOURCE

MCP 788

CODING FORM

AUTHOR | PROGRAM NAME | PROGRAM NUMBER – | DATE | PAGE OF

1-4	6-8	18-23	32	34-35	36-38	40-41	42-44	46	50-52	57-59
CARD CODE	SITE IDENTIFICATION NUMBER	SITE NAME (SITE CODES 100-199)	SITE TYPE	LONGITUDE DEGREES	MINUTES AND TENTHS	LATITUDE DEGREES	MINUTES AND TENTHS	NO OF PURPOSES	SITE PROP OWNR	LAND AVAILABLE ACRE-UNIT
SITE										

CODING FORM

AUTHOR

PROGRAM NAME

PROGRAM NUMBER

DATE

PAGE OF

CARD CODE

LEVEL

%

PRC1

CODING FORM

AUTHOR	PROGRAM NAME	PROGRAM NUMBER	DATE	PAGE OF

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22–30	31	32–77	78–80
C	A	R	D																					
C	O	D	E					[illegible]								FINAL PERIOD AVAILABLE						SEQUENCE		[illegible]
						1		9		3		4		1		9		5		4				
P	R	C	2																					

CODING FORM

AUTHOR	PROGRAM NAME	PROGRAM NUMBER	DATE	PAGE OF

1–4	7–9
CARD CODE	LINE OF SOURCE CODE
LINKI	
LINKO	

MCP 700

CODING FORM

AUTHOR
PROG AM NAME
PROGRAM NUMBER
DATE
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OF

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

CARD CODE

PERIOD SEGMENT

CAPITAL SLOPE

CAPITAL INTERCEPT

OPERATING SLOPE

OPERATING INTERCEPT

PROCESS ID CODE

PRCOST

MCP 780

CODING FORM

AUTHOR | PROGRAM NAME | PROGRAM NUMBER | DATE | PAGE OF

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

CARD

CODE

SITE IDENT NUMBER

PROCESS IDENT NUMBER

AMOUNTS OF PROCESS

CAPACITY IN 1000 POUND

MEASURE PER INPUT TIME FOR PERIOD

PROCESS LEVEL

SIPROC

MCP 788

CODING FORM

AUTHOR
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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

CARD CODE
TYPE CODE
ORIGIN ID CODE
ORIGIN/ PROCESS CODE
DESTINATION ID CODE
ONE-WAY TRAVEL TIME IN MINUTES
ONE WAY DISTANCE IN MILES
TRAVEL SPEED MPH

TRANS

MCP 788

CODING FORM

AUTHOR

PROGRAM NAME

PROGRAM NUMBER

DATE

PAGE
OF

CARD CODE	SITE ID CODE (COL < 3)	MAX TRUCKS PER YEAR PER PERIOD	
	1	2 3	4
TRUCK	●	● ●	●

CHAPTER 4

INTERPRETING THE MODEL OUTPUTS

Algorithm Outputs

The SWAP program, \the subroutine of WRAP which contains the fixed-charge linear programming algorithm, has outputs controlled by the entry in column 15 of the (WRAP) control card. This chapter will discuss the complete output printing option (obtained by entering 1 in column 15 of the control card). An entry of 2 provides only a summary of the size of the matrix (number of rows, number of columns, number of non-zero coefficients including slacks and artificials) and the output of the last phase (i.e., phase 3 outputs are suppressed if phase 4 is last-phase). An entry of 3 provides the same information as an entry of 2, except that intermediate phase outputs (i.e., phase 3 if phase 4 is last-phase) are not suppressed.

It should be noted that the static and dynamic modes are not differentiated in SWAP, but only in the structure of the matrix, right hand sides, and costs that are presented to SWAP. Thus, there is no mention of whether the mode is static or dynamic in SWAP outputs.

SWAP Summary

A summary is provided which indicates

1. last phase
2. (if last-phase is 4) whether single or double forcing
3. whether steepest descent was selected.

SWAP summaries are shown for N. E. Mass. B-2, representing the last-phase = 4 format, and for St. Louis G, representing the last-phase = 3 format. Note that N. E. Mass. B-2 was a static run, and St. Louis G was a dynamic run, but that differentiation does not appear in the summary.

Row Data (Right-hand Sides)

These data indicate the number of rows. For each, the row number, type, and right-hand side are shown. Type 0 is an equation and type 1 is a less-than-or-equal constraint. Type 2, which never appears in WRAP, is a greater-than-or equal constraint.

Row data are displayed for N. E. Mass. B-2 and St. Louis G.

The asterisks in row 60 of N. E. Mass. B-2 and row 77 of St. Louis G represent a very large right-hand side for the capacitation, n.e.c., constraint.

In the N. E. Mass. run B-2 row data, the first 14 rows are source balance equations; rows 15-17 are site processing constraints; rows 18-56 are input and output balance equations; rows 57-59 are truck constraints.

In St. Louis G row data, rows 1-8, 20-27, 39-46 and 58-65 are source balance equations; rows 9-19, 28-38, 47-57 and 66-76 are input and output balance equations; rows 78-114 are site/process capacity balance equations, and row 115 is a land constraint.

Column Data (costs)

These data indicate the number of columns. For each, an index, a column number, a variable cost, and a fixed cost are shown. The index is the sequential number of the column. The column number is equal to the index except for slacks and artificials. For slacks (one for each type 1 row -- i.e., less-than-or-equal constraint) the column number is 3000 plus the number of the type 1 row to which the slack corresponds. Artificials (one for each type 0 row -- i.e., equation) exist only for purposes of phase 1, which, along with phase 2, is bypassed by WRAP. For these columns, the column number is 2000 plus the number of the type 0 row to which the artificial corresponds.

The full set of column data of N. E. Mass. run B-2 follows.

The first 98 columns are transportation activities with only variable costs. Of these, the last 11 are type 5 transportation activities representing dummy shipments for collocated sites. These show zero variable and fixed costs. Columns 99 through 148 are processing activities which potentially may have both variable and fixed costs. Of these, the last 6 are dummy activities which differentiate the appropriate heavy end and incinerator residue revenues in secondary processing. The variable cost here is the negative of the appropriate revenue, and the fixed cost is zero. Index 149-155 is the set of slacks, and index 156-208 is the set of artificials.

Matrix

The A matrix is the set of equations for the model in coefficient form. A row is an equation, a column is an unknown, a right-hand side is the information to the right of the equals sign.

The A matrix is presented in row within column sort. This matrix includes slacks, but not artificials. The index, row number, column number, and value are shown. The index is the sequential number of the coefficient. The column number is the index (i.e., sequential number of the column) of the column data set. The value is the coefficient. The number of non-zero elements of the A matrix (including slacks but not artificials) is inserted at the head of the matrix.

The first page of the matrix of N. E. Mass. Run B-2 is shown.

User-Supplied Initial Basis

Despite the title, this set of data includes the initial basis whether supplied by the user or generated in the WRAP advanced starting point algorithm. The basis lists column numbers only, and uses the column number form of identification (i.e., slacks are 3000 plus the corresponding row number).

The initial basis from N. E. Mass. B-2 follows. (This basis was hand-generated and differs slightly from what would have been generated from the sample input if the automatic starting point algorithm had been used.)

Intermediate and Final Solutions

Intermediate and final solutions show a phase number, an objective value (in thousands of dollars per year in the static mode -- in thousands of dollars over the total planning period, discounted to the present, in the dynamic mode), and the solution. The solution lists column numbers of activities which are in the basis (i.e., slacks are 3000 plus the corresponding row number) and (activity) levels. The (activity) levels are thousands of tons per year in both the static mode and the dynamic mode except truck constraint slacks, which are in thousands of trucks per year, and land constraint slacks, which are in acre-feet. It should be noted that the solution as it is output from the algorithm is unsorted.

The phase 3 and phase 4 solutions of N. E. Mass. Run B-2 follow.

The WRAP Model Outputs

WRAP sorts and interprets the final solution and prints outputs which may not be varied by the user.

In the static mode, a single presentation is made, sorted in the order of sequential column number. The columns are grouped as follows:

1) type 1 transportation (source to ultimate)

2) type 2 transportation (source to intermediate)

3) type 3 transportation (intermediate to intermediate)

4) type 4 transportation (intermediate to ultimate)

5) type 5 transportation (activities which bypass the truck constraints such as rail haul and transportation between collocated sites)

6) processing activities.

The display is headed by a total system cost (in thousands of dollars per year) and by a system cost per ton, (in dollars per ton).

The full WRAP output of N. E. Mass. (static) run B-2 is presented below in Chapter 7.

In the dynamic mode, two sorts are presented, neither of which is sequential column order:

model period major sort and model period inner sort.

In the former, within model period, activities are sorted in sequential column order, and are grouped as follows:

1) type 1 transportation (source to ultimate)

2) type 2 transportation (source to intermediate)

3) type 3 transportation (intermediate to intermediate)

4) type 4 transportation (intermediate to ultimate)

5) type 5 transportation (activities which bypass the truck constraints such as rail haul and transportation between collocated sites)

6) processing activities

7) capacity building activity levels

8) capacity underutilization activity levels

after the presentation of all model periods:

9) land constraint slack activity levels (in acre-feet) (This displays land remaining at each site at the end of the planning period.)

The model period major sort presentation is preceded by an objective function value measuring the discounted system cost over the planning period in thousands of dollars.

In the model period inner sort, the nine groupings of activity levels become the major sort, and model period is the innermost sort within each group (except land remaining). The sequential column order is the intermediate sort.

The model period inner sort is preceded by a repetition of the objective function value, as in the model period major sort.

The full WRAP output of St. Louis (dynamic) run G is presented below in Chapter 7.

All activity levels, in both static and dynamic modes, are in thousands of tons per year except land remaining, which is in acre-feet.

In the WRAP output, slacks are suppressed except for the land constraint slack in the dynamic mode. In the Chapter 7 WRAP outputs, basic activities with zero activity levels are included; however, in the final version of WRAP, printout of such activities has been suppressed.

Maps

The use of maps to interpret and display WRAP outputs is essential. One method which can be used effectively utilizes a pair of maps to display each static run and each model period of a dynamic run. The first map in the pair displays flows from source to initial offload point. Each district centroid is shown, and is connected to its initial offload point by an arrow. The second map in the pair shows the location of active transfer, primary, secondary, and landfill sites, and differentiates the following kinds of flows:

- truck transfer flows
- rail transfer flows
- flows from primary processing to secondary processing
- fuel flows.

Transfer locations are coded T; primary processing locations are coded P; secondary processing locations are coded S; and landfill locations are coded L.

A full set of maps is included below in Chapter 5 for static run N. E. Mass. B-2 (2 maps) and for dynamic run St. Louis G (8 maps). Note that fuel flows are undefined in the Massachusetts runs.

N. E. Mass. B-2 Static

```
SWAP PROCESSING WILL BE TERMINATED AFTER PHASE 4

1 COLUMN(S) WILL BE FORCED INTO THE BASIS DURING EACH PHASE 4 FORCING TRIAL

STEEPEST DESCENT WILL BE USED IN EACH PHASE
```

St. Louis Dynamic

```
SWAP PROCESSING WILL BE TERMINATED AFTER PHASE 3
STEEPEST DESCENT WILL BE USED IN EACH PHASE
```

N. E. Mass. B-2 Row Data

```
DATA FOR THE   60 ROWS

ROW NUMBER     TYPE     RIGHT HAND SIDE

     1           0            94.900
     2           0            73.900
     3           0            27.700
     4           0            21.700
     5           0             6.000
     6           0            22.900
     7           0            64.600
     8           0            19.200
     9           0            25.700
    10           0            54.000
    11           0            57.600
    12           0            93.000
    13           0             5.700
    14           0            36.300
    15           1          1000.000
    16           1          1000.000
    17           1          1000.000
    18           0             0.0
    19           0             0.0
    20           0             0.0
    21           0             0.0
    22           0             0.0
    23           0             0.0
    24           0             0.0
    25           0             0.0
    26           0             0.0
    27           0             0.0
    28           0             0.0
    29           0             0.0
    30           0             0.0
    31           0             0.0
    32           0             0.0
    33           0             0.0
    34           0             0.0
    35           0             0.0
    36           0             0.0
    37           0             0.0
    38           0             0.0
    39           0             0.0
    40           0             0.0
    41           0             0.0
```

N. E. Mass. B-2 Row Data (concluded)

```
ROW NUMBER     TYPE     RIGHT HAND SIDE

    42          0            0.0
    43          0            0.0
    44          0            0.0
    45          0            0.0
    46          0            0.0
    47          0            0.0
    48          0            0.0
    49          0            0.0
    50          0            0.0
    51          0            0.0
    52          0            0.0
    53          0            0.0
    54          0            0.0
    55          0            0.0
    56          0            0.0
    57          1          390.000
    58          1          390.000
    59          1          390.000
    60          1       **********
```

St. Louis G Row Data

```
     DATA FOR THE  115 ROWS

ROW NUMBER     TYPE     RIGHT HAND SIDE

     1          0          39.100
     2          0          65.500
     3          0         280.100
     4          0          10.200
     5          0          79.300
     6          0         358.200
     7          0         795.300
     8          0         838.700
     9          0            0.0
    10          0            0.0
    11          0            0.0
    12          0            0.0
    13          0            0.0
    14          0            0.0
    15          0            0.0
    16          0            0.0
    17          0            0.0
    18          0            0.0
    19          0            0.0
    20          0          50.800
    21          0          90.600
    22          0         361.700
    23          0          14.800
    24          0         114.600
    25          0         449.100
    26          0         895.600
    27          0        1075.300
    28          0            0.0
    29          0            0.0
    30          0            0.0
    31          0            0.0
    32          0            0.0
    33          0            0.0
    34          0            0.0
    35          0            0.0
    36          0            0.0
    37          0            0.0
    38          0            0.0
    39          0          75.900
```

St. Louis G Row Data (continued)

ROW NUMBER	TYPE	RIGHT HAND SIDE
40	0	148.500
41	0	539.800
42	0	25.100
43	0	195.300
44	0	636.100
45	0	1070.300
46	0	1582.200
47	0	0.0
48	0	0.0
49	0	0.0
50	0	0.0
51	0	0.0
52	0	0.0
53	0	0.0
54	0	0.0
55	0	0.0
56	0	0.0
57	0	0.0
58	0	98.800
59	0	202.400
60	0	702.300
61	0	34.800
62	0	271.000
63	0	803.400
64	0	1205.400
65	0	2042.200
66	0	0.0
67	0	0.0
68	0	0.0
69	0	0.0
70	0	0.0
71	0	0.0
72	0	0.0
73	0	0.0
74	0	0.0
75	0	0.0
76	0	0.0
77	1	**********
78	0	0.0
79	0	0.0
80	0	0.0
81	0	0.0
82	0	0.0
83	0	0.0
84	0	0.0
85	0	0.0
86	0	0.0
87	0	0.0
88	0	0.0
89	0	0.0
90	0	0.0
91	0	0.0
92	0	0.0
93	0	0.0
94	0	0.0
95	0	0.0
96	0	0.0
97	0	0.0
98	0	0.0
99	0	0.0
100	0	0.0
101	0	0.0
102	0	0.0
103	0	0.0
104	0	0.0
105	0	0.0

St. Louis G Row Data (concluded)

ROW NUMBER	TYPE	RIGHT HAND SIDE
106	0	0.0
107	0	0.0
108	0	0.0
109	0	0.0
110	0	0.0
111	0	0.0
112	0	0.0
113	0	0.0
114	0	0.0
115	1	20000.000

Column Data for Mass. B-2

DATA FOR THE 208 COLUMNS

INDEX	COLUMN NUMBER	VARIABLE COST	FIXED COST
1	1	0.316	0.0
2	2	4.226	0.0
3	3	1.356	0.0
4	4	2.938	0.0
5	5	7.571	0.0
6	6	3.413	0.0
7	7	2.531	0.0
8	8	7.322	0.0
9	9	5.921	0.0
10	10	0.452	0.0
11	11	5.627	0.0
12	12	9.356	0.0
13	13	5.582	0.0
14	14	4.678	0.0
15	15	5.899	0.0
16	16	14.328	0.0
17	17	11.639	0.0
18	18	1.695	0.0
19	19	7.006	0.0
20	20	4.610	0.0
21	21	5.740	0.0
22	22	1.966	0.0
23	23	6.757	0.0
24	24	1.514	0.0
25	25	10.690	0.0
26	26	6.757	0.0
27	27	2.757	0.0
28	28	3.797	0.0
29	29	7.187	0.0
30	30	3.955	0.0
31	31	5.085	0.0
32	32	0.452	0.0
33	33	5.605	0.0
34	34	5.786	0.0
35	35	5.853	0.0
36	36	8.565	0.0
37	37	4.520	0.0
38	38	8.882	0.0
39	39	4.995	0.0
40	40	5.514	0.0
41	41	2.328	0.0
42	42	8.498	0.0
43	43	10.848	0.0
44	44	0.972	0.0
45	45	3.302	0.0

Column Data for Mass. B-2 (continued)

INDEX	COLUMN NUMBER	VARIABLE COST	FIXED COST
46	45	2.215	0.0
47	47	3.838	0.0
48	48	1.570	0.0
49	49	0.946	0.0
50	50	2.080	0.0
51	51	1.732	0.0
52	52	2.096	0.0
53	53	2.356	0.0
54	54	1.992	0.0
55	55	2.356	0.0
56	56	1.992	0.0
57	57	1.882	0.0
58	58	2.912	0.0
59	59	3.130	0.0
60	60	1.815	0.0
61	61	1.882	0.0
62	62	1.815	0.0
63	63	3.130	0.0
64	64	3.531	0.0
65	65	2.912	0.0
66	66	3.432	0.0
67	67	1.794	0.0
68	68	3.531	0.0
69	69	1.794	0.0
70	70	3.432	0.0
71	71	1.992	0.0
72	72	3.130	0.0
73	73	2.704	0.0
74	74	1.992	0.0
75	75	2.704	0.0
76	76	1.690	0.0
77	77	1.784	0.0
78	78	1.810	0.0
79	79	3.271	0.0
80	80	1.721	0.0
81	81	3.203	0.0
82	82	2.356	0.0
83	83	2.704	0.0
84	84	2.356	0.0
85	85	2.704	0.0
86	86	.356	0.0
87	87	2.704	0.0
88	88	0.0	0.0
89	89	0.0	0.0
90	90	0.0	0.0
91	91	0.0	0.0
92	92	0.0	0.0
93	93	0.0	0.0
94	94	0.0	0.0
95	95	0.0	0.0
96	96	0.0	0.0
97	97	0.0	0.0
98	98	0.0	0.0
99	99	0.702	78.000
100	100	0.409	121.000
101	101	0.702	79.000
102	102	0.409	121.000
103	103	-3.027	988.000
104	104	-3.862	1808.000
105	105	-1.243	1829.000
106	106	-3.910	3224.000
107	107	-0.547	624.000
108	108	1.442	36.000
109	109	0.702	79.000
110	110	0.241	387.000

Column Data for Mass. B-2 (continued)

INDEX	COLUMN NUMBER	VARIABLE COST	FIXED COST
111	111	-3.027	988.000
112	112	-8.100	1092.290
113	113	1.442	36.000
114	114	0.702	78.000
115	115	0.241	387.000
116	116	-3.027	988.000
117	117	-8.100	1092.290
118	118	0.702	78.000
119	119	0.409	121.000
120	120	-3.027	988.000
121	121	-3.862	1808.000
122	122	-0.547	624.000
123	123	0.702	78.000
124	124	0.409	121.000
125	125	5.271	265.000
126	126	2.760	950.000
127	127	0.702	78.000
128	128	0.409	121.000
129	129	-3.027	988.000
130	130	-3.862	1808.000
131	131	-1.243	1829.000
132	132	-3.910	3224.000
133	133	-0.547	624.000
134	134	4.360	331.700
135	135	2.150	573.500
136	136	1.200	917.600
137	137	4.360	135.130
138	138	2.150	376.930
139	139	1.200	721.030
140	140	4.360	331.700
141	141	2.150	573.500
142	142	1.200	917.600
143	143	-19.345	0.0
144	144	-19.345	0.0
145	145	-19.345	0.0
146	146	-30.077	0.0
147	147	-30.077	0.0
148	148	-30.077	0.0
149	3015	0.0	0.0
150	3016	0.0	0.0
151	3017	0.0	0.0
152	3057	0.0	0.0
153	3058	0.0	0.0
154	3059	0.0	0.0
155	3060	0.0	0.0
156	2001	0.0	0.0
157	2002	0.0	0.0
158	2003	0.0	0.0
159	2004	0.0	0.0
160	2005	0.0	0.0
161	2006	0.0	0.0
162	2007	0.0	0.0
163	2008	0.0	0.0
164	2009	0.0	0.0
165	2010	0.0	0.0
166	2011	0.0	0.0
167	2012	0.0	0.0
168	2013	0.0	0.0
169	2014	0.0	0.0
170	2018	0.0	0.0
171	2019	0.0	0.0
172	2020	0.0	0.0
173	2021	0.0	0.0
174	2022	0.0	0.0

Column Data for Mass. B-2 (continued)

INDEX	COLUMN NUMBER	VARIABLE COST	FIXED COST
175	2023	0.0	0.0
176	2024	0.0	0.0
177	2025	0.0	0.0
178	2026	0.0	0.0
179	2027	0.0	0.0
180	2028	0.0	0.0
181	2029	0.0	0.0
182	2030	0.0	0.0
183	2031	0.0	0.0
184	2032	0.0	0.0
185	2033	0.0	0.0
186	2034	0.0	0.0
187	2035	0.0	0.0
188	2036	0.0	0.0
189	2037	0.0	0.0
190	2038	0.0	0.0
191	2039	0.0	0.0
192	2040	0.0	0.0
193	2041	0.0	0.0
194	2042	0.0	0.0
195	2043	0.0	0.0
196	2044	0.0	0.0
197	2045	0.0	0.0
198	2046	0.0	0.0
199	2047	0.0	0.0
200	2048	0.0	0.0
201	2049	0.0	0.0
202	2050	0.0	0.0
203	2051	0.0	0.0
204	2052	0.0	0.0
205	2053	0.0	0.0
206	2054	0.0	0.0
207	2055	0.0	0.0
208	2056	0.0	0.0

Matrix

```
THE    394 NON-ZERO ELEMENTS OF THE A-MATRIX
INDEX        ROWNO.     COLUMNNO.      VALUE
   1              1             1       1.00
   2             18             1       1.00
   3              1             2       1.00
   4             26             2       1.00
   5             59             2       0.20
   6              2             3       1.00
   7             19             3       1.00
   8              2             4       1.00
   9             20             4       1.00
  10             57             4       0.20
  11              2             5       1.00
  12             26             5       1.00
  13             59             5       0.20
  14              3             6       1.00
  15             19             6       1.00
  16              3             7       1.00
  17             20             7       1.00
  18             57             7       0.20
  19              3             8       1.00
  20             26             8       1.00
  21             59             8       0.20
  22              4             9       1.00
  23             20             9       1.00
  24             57             9       0.20
  25              4            10       1.00
  26             21            10       1.00
  27              4            11       1.00
  28             26            11       1.00
  29             59            11       0.20
  30              5            12       1.00
  31             20            12       1.00
  32             57            12       0.20
  33              5            13       1.00
  34             21            13       1.00
  35              5            14       1.00
  36             22            14       1.00
  37              5            15       1.00
  38             26            15       1.00
  39             59            15       0.20
  40              6            16       1.00
  41             20            16       1.00
  42             57            16       0.20
  43              6            17       1.00
  44             21            17       1.00
  45              6            18       1.00
  46             22            18       1.00
  47              6            19       1.00
  48             26            19       1.00
  49             59            19       0.20
  50              7            20       1.00
  51             19            20       1.00
  52              7            21       1.00
  53             20            21       1.00
  54             57            21       0.20
  55              7            22       1.00
  56             23            22       1.00
  57             58            22       0.20
  58              8            23       1.00
  59             20            23       1.00
  60             57            23       0.20
  61              8            24       1.00
```

User-Supplied Initial Basis of Mass. B-2

```
THE USER-SUPPLIED INITIAL BASIS CONSISTS OF THE FOLLOWING ACTIVITIES
                   1                 144
                   4                 145
                   7                 146
                  10                 147
                  13                 148
                  18                  45
                  22                  49
                  24                  88
                  27                  89
                  32                  57
                  35                  61
                  37                  64
                  41                  68
                  44                  71
                3015                  74
                3016                  76
                3017                  79
                 100                  82
                 101                  84
                 104                  86
                 108                  93
                 113                  94
                 119                  95
                 123                  96
                 125                  97
                 128                  98
                 135                3057
                 137                3058
                 140                3059
                 143                3060
```

The Phase 3 Solution

```
THE OBJECTIVE VALUE IS         1512.8721

      1 IS BASIC AT LEVEL              94.9000
      4 IS BASIC AT LEVEL              78.9000
      7 IS BASIC AT LEVEL              27.9000
     10 IS BASIC AT LEVEL              21.7000
     13 IS BASIC AT LEVEL               6.0000
     18 IS BASIC AT LEVEL              22.9000
     22 IS BASIC AT LEVEL              64.6000
     24 IS BASIC AT LEVEL              19.2000
     27 IS BASIC AT LEVEL              26.7000
     32 IS BASIC AT LEVEL              54.0000
     35 IS BASIC AT LEVEL              57.6000
     37 IS BASIC AT LEVEL              93.0000
     41 IS BASIC AT LEVEL               5.7000
     44 IS BASIC AT LEVEL              36.3000
   3015 IS BASIC AT LEVEL             977.6611
   3016 IS BASIC AT LEVEL             981.5322
   3017 IS BASIC AT LEVEL             800.0000
     99 IS BASIC AT LEVEL              54.9000
    101 IS BASIC AT LEVEL               0.0
    103 IS BASIC AT LEVEL             516.3992
    108 IS BASIC AT LEVEL              27.7000
    113 IS BASIC AT LEVEL              22.9000
    118 IS BASIC AT LEVEL             110.5000
    123 IS BASIC AT LEVEL              54.0000
    125 IS BASIC AT LEVEL              93.0000
    127 IS BASIC AT LEVEL              42.0000
    134 IS BASIC AT LEVEL              90.3819
    137 IS BASIC AT LEVEL               0.0
```

The Phase 3 Solution (concluded)

```
 140 IS BASIC AT LEVEL           0.0
 143 IS BASIC AT LEVEL          23.2500
 144 IS BASIC AT LEVEL           0.0
 145 IS BASIC AT LEVEL           0.0
 146 IS BASIC AT LEVEL          67.1319
 147 IS BASIC AT LEVEL           0.0
 148 IS BASIC AT LEVEL           0.0
  45 IS BASIC AT LEVEL          94.9000
  49 IS BASIC AT LEVEL           0.0
  88 IS BASIC AT LEVEL          67.1319
  89 IS BASIC AT LEVEL           0.0
  57 IS BASIC AT LEVEL          27.7000
  61 IS BASIC AT LEVEL           0.0
  64 IS BASIC AT LEVEL          22.9000
  68 IS BASIC AT LEVEL           0.0
  71 IS BASIC AT LEVEL         110.5000
  74 IS BASIC AT LEVEL           0.0
  76 IS BASIC AT LEVEL          54.0000
  79 IS BASIC AT LEVEL          23.2500
  82 IS BASIC AT LEVEL          42.0000
  84 IS BASIC AT LEVEL           0.0
  86 IS BASIC AT LEVEL           0.0
  93 IS BASIC AT LEVEL          23.2500
  94 IS BASIC AT LEVEL           0.0
  95 IS BASIC AT LEVEL           0.0
  96 IS BASIC AT LEVEL          67.1319
  97 IS BASIC AT LEVEL           0.0
  98 IS BASIC AT LEVEL           0.0
3057 IS BASIC AT LEVEL         335.0457
3058 IS BASIC AT LEVEL         361.3997
3059 IS BASIC AT LEVEL         379.1292
3060 IS BASIC AT LEVEL    89999824.0000
```

The Phase 4 Solution

```
THE OBJECTIVE VALUE IS        1448.4475

     1 IS BASIC AT LEVEL.           94.9000
     4 IS BASIC AT LEVEL            78.9000
     7 IS BASIC AT LEVEL            27.9000
    10 IS BASIC AT LEVEL            21.7000
    13 IS BASIC AT LEVEL             5.0000
    18 IS BASIC AT LEVEL            22.9000
    22 IS BASIC AT LEVEL            64.6000
    24 IS BASIC AT LEVEL            19.2000
    27 IS BASIC AT LEVEL            26.7000
    32 IS BASIC AT LEVEL            54.0000
    35 IS BASIC AT LEVEL            57.6000
    37 IS BASIC AT LEVEL            93.0000
    41 IS BASIC AT LEVEL             5.7000
    44 IS BASIC AT LEVEL            36.3000
  3015 IS BASIC AT LEVEL           977.6611
  3016 IS BASIC AT LEVEL           981.5322
  3017 IS BASIC AT LEVEL           800.0000
    99 IS BASIC AT LEVEL            94.9000
   101 IS BASIC AT LEVEL             0.0
   103 IS BASIC AT LEVEL           516.3992
   108 IS BASIC AT LEVEL            27.7000
   113 IS BASIC AT LEVEL            22.9000
   118 IS BASIC AT LEVEL           110.5000
   123 IS BASIC AT LEVEL            54.0000
   125 IS BASIC AT LEVEL            93.0000
   127 IS BASIC AT LEVEL            42.0000
    81 IS BASIC AT LEVEL            23.2500
```

The Phase 4 Solution (concluded)

```
 137 IS BASIC AT LEVEL          90.3819
 140 IS BASIC AT LEVEL           0.0
 143 IS BASIC AT LEVEL           0.0
 144 IS BASIC AT LEVEL           0.0
 145 IS BASIC AT LEVEL          23.2500
  54 IS BASIC AT LEVEL          67.1319
 147 IS BASIC AT LEVEL           0.0
 148 IS BASIC AT LEVEL          67.1319
  45 IS BASIC AT LEVEL          94.9000
  49 IS BASIC AT LEVEL           0.0
  88 IS BASIC AT LEVEL           0.0
  89 IS BASIC AT LEVEL           0.0
  57 IS BASIC AT LEVEL          27.7000
  61 IS BASIC AT LEVEL           0.0
  64 IS BASIC AT LEVEL          22.9000
  68 IS BASIC AT LEVEL           0.0
  71 IS BASIC AT LEVEL         110.5000
  74 IS BASIC AT LEVEL           0.0
  75 IS BASIC AT LEVEL          54.0000
  79 IS BASIC AT LEVEL           0.0
  82 IS BASIC AT LEVEL          42.0000
  84 IS BASIC AT LEVEL           0.0
  86 IS BASIC AT LEVEL           0.0
  93 IS BASIC AT LEVEL           0.0
  94 IS BASIC AT LEVEL           0.0
  95 IS BASIC AT LEVEL          23.2500
  96 IS BASIC AT LEVEL           0.0
  97 IS BASIC AT LEVEL           0.0
  98 IS BASIC AT LEVEL          67.1319
3057 IS BASIC AT LEVEL         332.4641
3058 IS BASIC AT LEVEL         356.0830
3059 IS BASIC AT LEVEL         379.1292
3060 IS BASIC AT LEVEL    89999824.0000
```

CHAPTER 5

SAMPLE INPUTS AND OUTPUTS

Full listings of inputs and outputs are presented below for N. E. Massachusetts B-2, representing a static case, and St. Louis G, representing a dynamic case. The outputs display activities which were in the solution with a zero activity level. Such activities are suppressed in the final version of WRAP.

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N. E. Mass. B-2 Static Case

Inputs

```
CONTRL  1 4 1 1 2 2 2 0 0 2 2 1  14  18 8  29 098  3   020 20 20              5 17
TITLE NE MASSACHUSETTS CASE B-2 - - HALF TONNAGE
SOURCE101 SOUTH ESSEX OUTER  7055642299  949                    113
SOURCE102 LAWRENCE           7110042421  789                    113
SOURCE103 HAVERHILL          7104542465  279                    113
SOURCE104 NEWBURYPORT        7054942492  217                    113
SOURCE105 E CENTRAL ESSEX    7052042416   60                    113
SOURCE106 GLOUCESTER         7038442372  229                    113
SOURCE107 LOWELL EAST        7119242380  646                    113
SOURCE108 LOWELL WEST        7124342374  192                    113
SOURCE109 LOWELL SOUTH       7117042325  267                    113
SOURCE110 EAST MIDDLESEX     7109342346  54                     113
SOURCE111 NEW HAMPSHIRE      7119042510  576                    113
SOURCE112 RESCO COMMUNITIES  7058842269  93                     113
SOURCE113 S W CENTRAL ESSEX  7056442381   57                    113
SOURCE114 SOUTH ESSEX INNER  7059042329  363                    113
SITE 501 SALEM INCINERATOR/TR  1 70556 42299 1
SITE 502 LAWRENCE INCIN/TRANS  1 71083 42428 1
SITE 503 HAVERHILL PROCESSING  1 71073 42457 3
SITE 504 NEWBURYPORT TR/PROC   2 70549 42492 3
SITE 506 GLOUCESTER TR/PROC    2 70433 42371 3
SITE 507 LOWELL INCIN/TR/PROC  1 71214 42377 3
SITE 510 EA MIDDLESEX TRANS    1 71093 42346 1
SITE 512 RESCO PROCESSING      2 70588 42269 1
SITE 514 SO ESSEX INNER TR/PR  1 70587 42336 4
SITE 603 HAVERHILL SCDY RECOV  1 71073 42457 3
SITE 607 LOWELL EA SCDY RECOV  1 71214 42377 3 -19657
SITE 614 SO ESX INR SCDY RECV  1 70587 42336 3
SITE 633 HAV DUMMY INCIN RES   1 71073 42457 1
SITE 634 SO EX DUMMY INCIN RS  1 70587 42336 1
SITE 637 LWL DUMMY INCIN RES   1 71214 42377 1
SITE 643 HAV DUMMY HEAVY END   1 71073 42457 1
SITE 644 SO EX DUM HEAVY END   1 70587 42336 1
SITE 647 LWLDUMMY HEAVY END    1 71214 42377 1
PRC1     901 TRANSFER STATION        A 2100     750 025
PRC2  2        1               3                                           901
LNKI    2   0                                                              901
LNKO  905 915 925 935    0                                                 901
PRCOST 11     77185        14         66346        22                      901
PRCOST 12     35962        275        3423         505                     901
PRCOST 13     12115        542        2875         668                     901
PRC1     905 SHREDDED FUEL           B 2 13    1000 026
PRC2  2        1               3                                           905
LNKI    2 901   0                                                          905
LNKO  946   0                                                              905
PRCOST 11    2980649     317        3070175     70                         905
PRCOST 12     908094     668        1374698     320                        905
PRCOST 13     441506     1098       150641      710                        905
PRC1     906 SECONDARY RECOVERY     C 2
PRC2  2        1               3                                           906
LNKI    1 936 946   0                                                      906
PRCOST 11    126          1767       31          155                       906
PRCOST 12     75          2015       14          372                       906
PRCOST 13     12          44485      108         47275                     906
PRC1     915 RESCO PROCESS           B 1 25    1200 026
PRC2  2        1               2                                           915
LNKI    2 901    0                                                         915
LNKO  936    0                                                             915
PRCOST 11    0                0      5271        265                       915
PRCOST 12    0                0      276         950                       915
PRC1     925 DRIED SHREDDED FUEL     B 2 13    1000 026
PRC2  2        1               3                                           925
LNKI    2 901    0                                                         925
LNXO  946    0                                                             925
PRCOST 11    45           234        935         386                       925
PRCOST 12    22           58125      446667      124775                    925
PRCOST 13    115        10261        285         21979                     925
```

N. E. Mass. B-2 Static Case (continued)

Inputs

```
PRC1    935 GAS PYROLYSIS     B 2
PRC2  2       1               2                                             935
LNKI     2 901   0                                                          935
PRCOST 11  0          38683    0         70546                              935
PRCOST 12  221333      2496    533967    3744                               935
PRC1    936 DUMMY INCIN RESIDUE      C 2100    1200 026
PRC2  2       1               1                                             936
LNKI    1 915    0                                                          936
LNKO  905    0                                                              936
PRCOST 11  0             0      0          0                                936
PRC1    946 DUMMY HEAVY END          C 2100    1000 026
PRC2  2       1               1                                             946
LNKI    1 905 925   0                                                       946
LNKO  906    0                                                              946
PRCOST 11  0.         0.       0.          0.                               946
SIPROC 501 901   23                                   A
SIPROC 502 901   23                                   A
SIPROC 503 905   23        581                        B
SIPROC 503 925   23        791                        B
SIPROC 503 935   02        810                        B
SIPROC 504 901   12 1240                              A
SIPROC 504 905   12 1240   581                        B
SIPROC 504 935   01   62   810                        B
SIPROC 506 901   12 1240                              A
SIPROC 506 905   12 1240   581                        B
SIPROC 506 935   01   62   810                        B
SIPROC 507 901   23                                   A
SIPROC 507 905   23        581                        B
SIPROC 507 935   02        810                        B
SIPROC 510 901   23                                   A
SIPROC 512 915   12  465    0                         B
SIPROC 514 901   23                                   A
SIPROC 514 905   23        581                        B
SIPROC 514 925   23        791                        B
SIPROC 514 935   02        810                        B
SIPROC 603 906   13                                   C
SIPROC 607 906   13                                   C
SIPROC 614 906   13                                   C
SIPROC 633 936   01        19345                      C
SIPROC 634 936   01        19345                      C
SIPROC 637 936   01        19345                      C
SIPROC 643 946   01        30077                      C
SIPROC 544 946   01        30077                      C
SIPROC 647 946   01        30077                      C
TRANS 2 101 101 501        14
TRANS 2 101 101 514       187
TRANS 2 102 102 502         6
TRANS 2 102 102 503       13
TRANS 2 102 102 514       335
TRANS 2 103 103 502       151
TRANS 2 103 103 503       112
TRANS 2 103 103 514       324
TRANS 2 104 104 503       262
TRANS 2 104 104 504         2
TRANS 2 104 104 514       249
TRANS 2 105 105 503       414
TRANS 2 105 105 504       247
TRANS 2 105 105 506       207
TRANS 2 105 105 514       261
TRANS 2 106 106 504       515
TRANS 2 106 106 506        75
TRANS 2 106 106 503       634
TRANS 2 106 106 514       31
TRANS 2 107 107 502       204
TRANS 2 107 107 503       254
TRANS 2 107 107 507        87
TRANS 2 108 108 503       299
TRANS 2 108 108 507        67
```

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N. E. Mass. B-2 Static Case (continued)

Inputs

```
TRANS 2 108 108 514     473
TRANS 2 109 109 503     299
TRANS 2 109 109 507     122
TRANS 2 109 109 510     168
TRANS 2 109 109 514     318
TRANS 2 110 110 502     175
TRANS 2 110 110 503     225
TRANS 2 110 110 510       2
TRANS 2 110 110 514     248
TRANS 2 111 111 502     256
TRANS 2 111 111 503     259
TRANS 2 111 111 507     379
TRANS 2 112 112 512     20
TRANS 2 113 113 503     393
TRANS 2 113 113 504     221
TRANS 2 113 113 506     244
TRANS 2 113 113 514     103
TRANS 2 114 114 503     376
TRANS 2 114 114 507     48
TRANS 2 114 114 514      43
TRANS 3 501 901 503     535
TRANS 3 501 901 506     326
TRANS 3 501 901 507     638
TRANS 3 501 901 514     202
TRANS 3 502 901 503      82
TRANS 3 502 901 504     30
TRANS 3 502 901 507     233
TRANS 3 502 901 514     303
TRANS 3 503 905 644     353
TRANS 3 503 905 647     283
TRANS 3 503 925 644     353
TRANS 3 503 925 647     283
TRANS 3 504 901 503     262
TRANS 3 504 901 506     46
TRANS 3 504 901 507     502
TRANS 3 504 901 514     249
TRANS 3 504 905 643     262
TRANS 3 504 905 644     249
TRANS 3 504 905 647     502
TRANS 3 506 901 503     579
TRANS 3 506 901 504     46
TRANS 3 504 901 507     56
TRANS 3 506 901 514     245
TRANS 3 506 905 643     579
TRANS 3 506 905 644     245
TRANS 3 506 905 647     56
TRANS 3 507 901 503     283
TRANS 3 507 901 504     502
TRANS 3 507 901 514     42
TRANS 3 507 905 643     283
TRANS 3 507 905 644     42
TRANS 3 510 901 503     225
TRANS 3 510 901 507     243
TRANS 3 510 901 514     248
TRANS 3 512 915 633     529
TRANS 3 512 915 634     231
TRANS 3 512 915 537     516
TRANS 3 514 901 503     353
TRANS 3 514 901 507     42
TRANS 3 514 905 643     353
TRANS 3 514 905 647     42
TRANS 3 514 925 643     353
TRANS 3 514 925 647     42
TRANS 5 503 905 643      -1
TRANS 5 503 925 643      -1
TRANS 5 507 905 647      -1
TRANS 5 514 905 644      -1
```

N. E. Mass. B-2 Static Case (concluded)

Inputs

```
TRANS 5 514 925 644         -1
TRANS 5 633 936 603         -1
TRANS 5 634 936 614         -1
TRANS 5 637 936 607         -1
TRANS 5 643 946 603         -1
TRANS 5 644 946 614         -1
TRANS 5 647 946 607         -1
TRUCK 503 633 643   390
TRUCK 507 637 647   390
TRUCK 514 634 644   390
    1    4    7   10   13   18   22   24   27   32   35   37   41   44  100  101
  104  108  113  119  123  125  128  135  137  140  143  144  145  146  147  148
   45   49   88   89   57   61   64   68   71   74   76   79   82   84   86   93
   94   95   96   97   98  149  150  151  152  153  154  156
```

N. E. Mass. B-2 Static Case

Outputs

```
OBJECTIVE VALUE IS    1448.4475 IN THOUSANDS OF DOLLARS PER YEAR INCLUDING ALL COSTS FROM LOADING OF PACKER TRUCKS

TOTAL TONNAGE IS     609.3994 IN THOUSANDS OF TONS PER YEAR

AVERAGE SYSTEM COST IS       2.3768 PER TON

                TRANSPORTATION ACTIVITY LEVEL DATA FOR THE SOURCE TO INTERMEDIATE FACILITY PAIR(S)
                            *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                                           ACTIVITY
              ORIGIN NAME        I D       DESTINATION NAME      I D         LEVEL *

            SOUTH ESSEX OUTER    101     SALEM INCINERATOR/TR   501         94.9000
            LAWRENCE             102     HAVERHILL PROCESSING   503         78.9000
            HAVERHILL            103     HAVERHILL PROCESSING   503         27.9000
            NEWBURYPORT          104     NEWBURYPORT TR/PROC    504         21.7000
            E CENTRAL ESSEX      105     NEWBURYPORT TR/PROC    504          6.0000
            GLOUCESTER           106     GLOUCESTER TR/PROC     506         22.9000
            LOWELL EAST          107     LOWELL INCIN/TR/PROC   507         64.6000
            LOWELL WEST          108     LOWELL INCIN/TR/PROC   507         19.2000
            LOWELL SOUTH         109     LOWELL INCIN/TR/PROC   507         26.7000
            EAST MIDDLESEX       110     EA MIDDLESEX TRANS     510         54.0000
            NEW HAMPSHIRE        111     HAVERHILL PROCESSING   503         57.6000
            RESCO COMMUNITIES    112     RESCO PROCESSING       512         93.0000
            S W CENTRAL ESSEX    113     SO ESSEX INNER TR/PR   514          5.7000
            SOUTH ESSEX INNER    114     SO ESSEX INNER TR/PR   514         36.3000

             TRANSPORTATION ACTIVITY LEVEL DATA FOR THE INTERMEDIATE TO INTERMEDIATE FACILITY PAIR(S)
                            *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

       ORIGIN SITE NAME      I D     ORIGIN PROCESS NAME  I D     DESTINATION SITE NAME I D          ACTIVITY
                                                                                                       LEVEL *

       SALEM INCINERATOR/TR  501    TRANSFER STATION      901     HAVERHILL PROCESSING  503          94.9000
       LAWRENCE INCIN/TRANS  502    TRANSFER STATION      901     HAVERHILL PROCESSING  503           0.0
       HAVERHILL PROCESSING  503    SHREDDED FUEL         905     LWLDUMMY HEAVY END    647          67.1319
       NEWBURYPORT TR/PROC   504    TRANSFER STATION      901     HAVERHILL PROCESSING  503          27.7000
       NEWBURYPORT TR/PROC   504    SHREDDED FUEL         905     HAV DUMMY HEAVY END   643           0.0
       GLOUCESTER TR/PROC    506    TRANSFER STATION      901     HAVERHILL PROCESSING  503          22.9000
       GLOUCESTER TR/PROC    506    SHREDDED FUEL         905     HAV DUMMY HEAVY END   643           0.0
       LOWELL INCIN/TR/PROC  507    TRANSFER STATION      901     HAVERHILL PROCESSING  503         110.5000
       LOWELL INCIN/TR/PROC  507    SHREDDED FUEL         905     HAV DUMMY HEAVY END   643           0.0
       EA MIDDLESEX TRANS    510    TRANSFER STATION      901     HAVERHILL PROCESSING  503          54.0000
       RESCO PROCESSING      512    RESCO PROCESS         915     HAV DUMMY INCIN RES   633           0.0
       RESCO PROCESSING      512    RESCO PROCESS         915     LWL DUMMY INCIN RES   637          23.2500
       SO ESSEX INNER TR/PR  514    TRANSFER STATION      901     HAVERHILL PROCESSING  503          42.0000
       SO ESSEX INNER TR/PR  514    SHREDDED FUEL         905     HAV DUMMY HEAVY END   643           0.0
       SO ESSEX INNER TR/PR  514    DRIED SHREDDED FUEL   925     HAV DUMMY HEAVY END   643           0.0
```

N. E. Mass. B-2 Static Case (continued)

Outputs

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                  TRANSPORTATION ACTIVITY LEVEL DATA FOR THE CATEGORY FIVE PAIR(S)
                       *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

ORIGIN SITE NAME       I D     ORIGIN PROCESS NAME    I D     DESTINATION SITE NAME I D        ACTIVITY
                                 WHERE APPLICABLE                                               LEVEL *

HAVERHILL PROCESSING   503    SHREDDED FUEL           905    HAV DUMMY HEAVY END    643            0.0
HAVERHILL PROCESSING   503    DRIED SHREDDED FUEL     925    HAV DUMMY HEAVY END    643            0.0
HAV DUMMY INCIN RES    633    DUMMY INCIN RESIDUE     936    HAVERHILL SCDY RECOV   603            0.0
SO EX DUMMY INCIN RS   634    DUMMY INCIN RESIDUE     936    SO ESX INR SCDY RECV   614            0.0
LWL DUMMY INCIN RES    637    DUMMY INCIN RESIDUE     936    LOWELL EA SCDY RECOV   607        23.2500
HAV DUMMY HEAVY END    643    DUMMY HEAVY END         946    HAVERHILL SCDY RECOV   603            0.0
SO EX DUM HEAVY END    644    DUMMY HEAVY END         946    SO ESX INR SCDY RECV   614            0.0
LWLDUMMY HEAVY END     647    DUMMY HEAVY END         946    LOWELL EA SCDY RECOV   607        67.1319


                                  PROCESSING ACTIVITY LEVELS
                       *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                                        ACTIVITY     LINEAR
      SITE NAME           I D      PROCESS NAME            I D            LEVEL *     SEGMENT

SALEM INCINERATOR/TR      501     TRANSFER STATION         901           94.9000        2
LAWRENCE INCIN/TRANS      502     TRANSFER STATION         901               0.0        2
HAVERHILL PROCESSING      503     SHREDDED FUEL            905          516.3992        2
NEWBURYPORT TR/PROC       504     TRANSFER STATION         901           27.7000        1
GLOUCESTER TR/PROC        506     TRANSFER STATION         901           22.9000        1
LOWELL INCIN/TR/PROC      507     TRANSFER STATION         901          110.5000        2
EA MIDDLESEX TRANS        510     TRANSFER STATION         901           54.0000        2
RESCO PROCESSING          512     RESCO PROCESS            915           93.0000        1
SO ESSEX INNER TR/PR      514     TRANSFER STATION         901           42.0000        2
LOWELL EA SCDY RECOV      607     SECONDARY RECOVERY       906           90.3819        1
SO ESX INR SCDY RECV      614     SECONDARY RECOVERY       906               0.0        1
HAV DUMMY INCIN RES       633     DUMMY INCIN RESIDUE      936               0.0        1
SO EX DUMMY INCIN RS      634     DUMMY INCIN RESIDUE      936               0.0        1
LWL DUMMY INCIN RES       637     DUMMY INCIN RESIDUE      936           23.2500        1
SO EX DUM HEAVY END       644     DUMMY HEAVY END          946               0.0        1
LWLDUMMY HEAVY END        647     DUMMY HEAVY END          946           67.1319        1
```

St. Louis G Dynamic Case

Inputs

```
CONTRL  2 4 1 1 2 1 2 0   2 1 4   8   7 4  10  30  0  0 20 25  3 10  7  5  5 17
CNTR2 104    943
TITLE ST. LOUIS DYNAMIC RUN CASE G
SOURCE101FRANKLIN COUNTY      9058238255  391  508  759  988113  113  113  113
SOURCE102JEFFERSON COUNTY     9028138193  655  906 1485 2024113  113  113  113
SOURCE103MADISON COUNTY       9003138497 2801 3617 5398 7023113  113  113  113
SOURCE104MONROE COUNTY        9009838211  102  148  251  348113  113  113  113
SOURCE105ST. CHARLES COUNTY   9032738471  793 1146 1953 2710113  113  113  113
SOURCE106ST. CLAIR COUNTY     8959538334 3582 4491 6361 8034113  113  113  113
SOURCE107ST. LOUIS CITY       9014638372 7953 89561070312054113  113  113  113
SOURCE108ST. LOUIS COUNTY     9021438401 83871079315822204221 13  113  113  113
SITE 501 M1 TRANS                1 91011 38268 1
SITE 506 M6 PROCESSING           1 90167 38349 2
SITE 507 M7 TRANS/PYROLYSIS      1 90388 38377 2
SITE 509 M9 TRANS                1 90422 38497 1
SITE 513 M10 TRANS/PYROLYSIS     1 90306 38308 2
SITE 514 U1 MKT/PROCESSING       1 90194 38260 1
SITE 711 A19 VIGUS QUARRY        1 90289 38447 1          20000
PRC1     901 TRANSFER PKR TO VAN    A 210      750 026    026    026    026   0
PRC2  2 2 2 2 3 4 4 4          3                                              901
LNKI    2   0                                                                 901
LNKO  907 935 955   0                                                         901
PRCOST 11      77885       14       66346       22                            901
PRCOST 12      35962      275        3423      505                            901
PRCOST 13      12115      542        2875      668                            901
PRCOST 21      77885       14       66346       22                            901
PRCOST 22      35962      275        3423      505                            901
PRCOST 23      12115      542        2875      668                            901
PRCOST 31      77885       14       66346       22                            901
PRCOST 32      35962      275        3423      505                            901
PRCOST 33      12115      542        2875      668                            901
PRCOST 41      77885       14       66346       22                            901
PRCOST 42      35962      275        3423      505                            901
PRCOST 43      12115      542        2875      668                            901
PRC1     907 SANITARY LANDFILL         D 2
PRC2  2 2 2 2 2 3 4 4          3                                              907
LNKI    2 901   0                                                             907
PRCOST 11     546875      8525    1640625     76725                           907
PRCOST 12     36          1395    108        125550                           907
PRCOST 13     2115       25575    6345       230175                           907
PRCOST 21     546875      8525    1640625     76725                           907
PRCOST 22     36          1395    108        125550                           907
PRCOST 23     2115       25575    6345       230175                           907
PRCOST 31     546875      8525    1640625     76725                           907
PRCOST 32     36          1395    108        125550                           907
PRCOST 33     2115       25575    6345       230175                           907
PRCOST 41     546875      8525    1640625     76725                           907
PRCOST 42     36          1395    108        125550                           907
PRCOST 43     2115       25575    6345       230175                           907
PRC1     935 GAS PYROLYSIS             B 2                              1
PRC2  1 2 2 2   4 4 4          1                                              935
LNKI    2 901   0                                                             935
PRCOST 11    221333     2496      533967      3744                            935
PRCOST 21    221333     2496      533967      3744                            935
PRCOST 31    221333     2496      533967      3744                            935
PRCOST 41    221333     2496      533967      3744                            935
PRC1     955 SHREDDED FUEL/SEC RC      B 2                              1
PRC2  2 2 2 2 3 4 4 4          3                                              955
LNKI    2 901   0                                                             955
PRCOST 11    3145       4937        3473       225                            955
PRCOST 12    1072       8447        2278       475                            955
PRCOST 13      54      12995        1688      1082                            955
PRCOST 21    3145       4937        3473       225                            955
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St. Louis G Dynamic Case (concluded)

Inputs

```
PRCOST 22    1072          8447       2278        475                                  955
PRCOST 23      54         12995       1688       1082                                  955
PRCOST 31    3145          4937       3473        225                                  955
PRCOST 32    1072          8447       2278        475                                  955
PRCOST 33      54         12995       1688       1082                                  955
PRCOST 41    3145          4937       3473        225                                  955
PRCOST 42    1072          8447       2278        475                                  955
PRCOST 43      54         12995       1688       1082                                  955
SIPROC 501 901     13                                          A
SIPROC 506 935     01                 1554     1554     1554   B
SIPROC 506 955     13         6732    6732     6732     6732   B
SIPROC 507 901     13                                          A
SIPROC 507 935     01                 1554     1554     1554   B
SIPROC 509 901     13                                          A
SIPROC 510 901     13                                          A
SIPROC 510 935     01                 1554     1554     1554   B
SIPROC 514 955     13         8447    8447     8447     8447   B
SIPROC 711 907     13                                          D
TRANS 1 103 103 711       48
TRANS 1 105 105 711      143
TRANS 1 108 108 711       25
TRANS 2 101 101 501       60
TRANS 2 102 102 506       45
TRANS 2 102 102 510       52
TRANS 2 102 102 514       25
TRANS 2 103 103 506      472
TRANS 2 103 103 507       43
TRANS 2 104 104 506       28
TRANS 2 104 104 507       29
TRANS 2 105 105 506      518
TRANS 2 105 105 509       18
TRANS 2 105 105 510      412
TRANS 2 106 106 506       40
TRANS 2 106 106 507       30
TRANS 2 107 107 506      120
TRANS 2 108 108 506      239
TRANS 2 108 108 510      239
TRANS 3 501 901 506       92
TRANS 3 501 901 510       60
TRANS 3 507 901 506       20
TRANS 3 507 901 510       36
TRANS 3 507 901 514      479
TRANS 3 509 901 506       60
TRANS 3 509 901 510      522
TRANS 3 510 901 506       32
TRANS 3 510 901 514       36
TRANS 4 509 901 711      255
TRANS 4 510 901 711      342
```

Outputs

```
                                          DYNAMIC MODEL OUTPUT

                                         MODEL PERIOD MAJOR SORT

OBJECTIVE VALUE IS -178939.3750 IN THOUSANDS OF DOLLARS DISCOUNTED TO YEAR ONE INCLUDING ALL COSTS FROM LOADING OF PACKER TRUCKS

                                        ACTIVITY DATA FOR MODEL PERIOD 1

                         TRANSPORTATION ACTIVITY LEVEL DATA FOR THE SOURCE TO ULTIMATE FACILITY PAIR(S)
                                    *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                                           ACTIVITY    MODEL
                ORIGIN NAME      I D    DESTINATION NAME       I D          LEVEL *    PERIOD

              MADISON COUNTY     103    A19 VIGUS QUARRY       711           0.0         1

                                        ACTIVITY DATA FOR MODEL PERIOD 1

                          TRANSPORTATION ACTIVITY LEVEL DATA FOR THE SOURCE TO INTERMEDIATE FACILITY PAIR(S)
                                     *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                                           ACTIVITY    MODEL
                ORIGIN NAME      I D    DESTINATION NAME       I D          LEVEL *    PERIOD

              FRANKLIN COUNTY    101    M1 TRANS               501          39.1000      1
              JEFFERSON COUNTY   102    M6 PROCESSING          506          65.5000      1
              JEFFERSON COUNTY   102    M10 TRANS/PYROLYSIS    510           0.0         1
              JEFFERSON COUNTY   102    U1 MKT/PROCESSING      514           0.0         1
              MADISON COUNTY     103    M6 PROCESSING          506         280.0999      1
              MADISON COUNTY     103    M7 TRANS/PYROLYSIS     507           0.0         1
              MONROE COUNTY      104    M6 PROCESSING          506          10.2000      1
              ST. CHARLES COUNTY 105    M6 PROCESSING          506          79.3000      1
              ST. CLAIR COUNTY   106    M6 PROCESSING          506         359.2000      1
              ST. LOUIS CITY     107    M6 PROCESSING          506         795.2996      1
              ST. LOUIS COUNTY   108    M6 PROCESSING          506         838.7000      1

                                  ACTIVITY DATA FUR MODEL PERIOD 1

                  TRANSPORTATION ACTIVITY LEVEL DATA FOR THE INTERMEDIATE TO INTERMEDIATE FACILITY PAIR(S)
                                 *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                                                                ACTIVITY    MODEL
ORIGIN SITE NAME      I D    ORIGIN PROCESS NAME  I D    DESTINATION SITE NAME I D               LEVEL *    PERIOD

M1 TRANS              501    TRANSFER PKR TO VAN  901    M6 PROCESSING         506              39.1000       1
M7 TRANS/PYROLYSIS    507    TRANSFER PKR TO VAN  901    M6 PROCESSING         506               0.0          1
M9 TRANS              509    TRANSFER PKR TO VAN  901    M6 PROCESSING         506               0.0          1
M10 TRANS/PYROLYSIS   510    TRANSFER PKR TO VAN  901    M6 PROCESSING         506               0.0          1
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                    ACTIVITY DATA FOR MODEL PERIOD 1

                       PROCESSING ACTIVITY LEVELS
             *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                              ACTIVITY    MODEL
   SITE NAME           I D       PROCESS NAME         I D      LEVEL *    PERIOD

M1 TRANS               501    TRANSFER PKR TO VAN     901      39.1000      1
M6 PROCESSING          506    SHREDDED FUEL/SEC RC    955    2466.3992      1
M7 TRANS/PYROLYSIS     507    TRANSFER PKR TO VAN     901       0.0         1
M9 TRANS               509    TRANSFER PKR TO VAN     901       0.0         1
M10 TRANS/PYROLYSIS    510    TRANSFER PKR TO VAN     901       0.0         1
U1 MKT/PROCESSING      514    SHREDDED FUEL/SEC RC    955       0.0         1
A19 VIGUS QUARRY       711    SANITARY LANDFILL       907       0.0         1


                    ACTIVITY DATA FOR MODEL PERIOD 1

                   CAPACITY BUILDING ACTIVITY LEVELS
             *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                      MODEL         ACTIVITY  LINEAR
   SITE NAME           I D       PROCESS NAME    I D  PERIOD         LEVEL *  SEGMENT

M1 TRANS               501    TRANSFER PKR TO VAN   901   1           75.9000     2
M6 PROCESSING          506    SHREDDED FUEL/SEC RC  955   1         2466.3992     3
M7 TRANS/PYROLYSIS     507    TRANSFER PKR TO VAN   901   1            0.0        1
M9 TRANS               509    TRANSFER PKR TO VAN   901   1            0.0        1
M10 TRANS/PYROLYSIS    510    TRANSFER PKR TO VAN   901   1            0.0        1
U1 MKT/PROCESSING      514    SHREDDED FUEL/SEC RC  955   1            0.0        1
A19 VIGUS QUARRY       711    SANITARY LANDFILL     907   1


                    ACTIVITY DATA FOR MODEL PERIOD 1

                CAPACITY UNDERUTILIZATION ACTIVITY LEVELS
             *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                      MODEL          ACTIVITY
   SITE NAME           I D       PROCESS NAME    I D  PERIOD          LEVEL *

M1 TRANS               501    TRANSFER PKR TO VAN   901   1           36.8000
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ACTIVITY DATA FOR MODEL PERIOD 2

TRANSPORTATION ACTIVITY LEVEL DATA FOR THE SOURCE TO INTERMEDIATE FACILITY PAIR(S)

*ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

ORIGIN NAME	I D	DESTINATION NAME	I D	ACTIVITY LEVEL *	MODEL PERIOD
FRANKLIN COUNTY	101	M1 TRANS	501	50.8000	2
JEFFERSON COUNTY	102	M6 PROCESSING	506	90.6000	2
JEFFERSON COUNTY	102	M10 TRANS/PYROLYSIS	510	0.0	2
JEFFERSON COUNTY	102	U1 MKT/PROCESSING	514	0.0	2
MADISON COUNTY	103	M7 TRANS/PYROLYSIS	507	361.6995	2
MONROE COUNTY	104	M7 TRANS/PYROLYSIS	507	14.8000	2
ST. CHARLES COUNTY	105	M9 TRANS	509	114.6000	2
ST. CLAIR COUNTY	106	M7 TRANS/PYROLYSIS	507	449.0999	2
ST. LOUIS CITY	107	M6 PROCESSING	506	895.5999	2
ST. LOUIS COUNTY	108	M6 PROCESSING	506	1075.2996	2

ACTIVITY DATA FOR MODEL PERIOD 2

TRANSPORTATION ACTIVITY LEVEL DATA FOR THE INTERMEDIATE TO INTERMEDIATE FACILITY PAIR(S)

*ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

ORIGIN SITE NAME	I D	ORIGIN PROCESS NAME	I D	DESTINATION SITE NAME	I D	ACTIVITY LEVEL *	MODEL PERIOD
M1 TRANS	501	TRANSFER PKR TO VAN	901	M6 PROCESSING	506	50.8000	2
M7 TRANS/PYROLYSIS	507	TRANSFER PKR TO VAN	901	M6 PROCESSING	506	0.0	2
M9 TRANS	509	TRANSFER PKR TO VAN	901	M6 PROCESSING	506	114.6000	2
M10 TRANS/PYROLYSIS	510	TRANSFER PKR TO VAN	901	M6 PROCESSING	506	0.0	2

ACTIVITY DATA FOR MODEL PERIOD 2

PROCESSING ACTIVITY LEVELS

*ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

SITE NAME	I D	PROCESS NAME	I D	ACTIVITY LEVEL *	MODEL PERIOD
M1 TRANS	501	TRANSFER PKR TO VAN	901	50.8000	2
M6 PROCESSING	506	GAS PYROLYSIS	935	2226.9987	2
M7 TRANS/PYROLYSIS	507	TRANSFER PKR TO VAN	901	0.0	2
M7 TRANS/PYROLYSIS	507	GAS PYROLYSIS	935	825.5989	2
M9 TRANS	509	TRANSFER PKR TO VAN	901	114.6000	2
M10 TRANS/PYROLYSIS	510	TRANSFER PKR TO VAN	901	0.0	2
M10 TRANS/PYROLYSIS	510	GAS PYROLYSIS	935	0.0	2
U1 MKT/PROCESSING	514	SHREDDED FUEL/SEC RC	955	0.0	2
A19 VIGUS QUARRY	711	SANITARY LANDFILL	907	0.0	2

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                              ACTIVITY DATA FOR MODEL PERIOD 2

                              CAPACITY BUILDING ACTIVITY LEVELS
                       *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                        MODEL            ACTIVITY  LINEAR
        SITE NAME        I D       PROCESS NAME     I D  PERIOD             LEVEL *  SEGMENT

  M6 PROCESSING          506    GAS PYROLYSIS       935    2             2226.8987     1
  M7 TRANS/PYROLYSIS     507    GAS PYROLYSIS       935    2              825.5989     1
  M9 TRANS               509    TRANSFER PKR TO VAN 901    2              271.0000     3
  M10 TRANS/PYROLYSIS    510    GAS PYROLYSIS       935    2                0.0        1

                              ACTIVITY DATA FOR MODEL PERIOD 2

                           CAPACITY UNDERUTILIZATION ACTIVITY LEVELS
                       *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                              MODEL              ACTIVITY
        SITE NAME           I D        PROCESS NAME        I D  PERIOD              LEVEL *

     M1 TRANS               501     TRANSFER PKR TO VAN    901    2                 25.1000
     M6 PROCESSING          506     SHREDDED FUEL/SEC RC   955    2               2466.3992
     M9 TRANS               509     TRANSFER PKR TO VAN    901    2                156.4000

                              ACTIVITY DATA FOR MODEL PERIOD 3

        TRANSPORTATION ACTIVITY LEVEL DATA FOR THE SOURCE TO ULTIMATE FACILITY PAIR(S)
                       *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                                         ACTIVITY    MODEL
      ORIGIN NAME          I D      DESTINATION NAME      I D               LEVEL *    PERIOD

  MADISON COUNTY           103     A19 VIGUS QUARRY       711                0.0         3

                              ACTIVITY DATA FOR MODEL PERIOD 3

        TRANSPORTATION ACTIVITY LEVEL DATA FOR THE SOURCE TO INTERMEDIATE FACILITY PAIR(S)
                       *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                                         ACTIVITY    MODEL
      ORIGIN NAME          I D      DESTINATION NAME      I D               LEVEL *    PERIOD

    FRANKLIN COUNTY        101     M1 TRANS               501              75.9000      3
    JEFFERSON COUNTY       102     M6 PROCESSING          506             148.5000      3
    MADISON COUNTY         103     M6 PROCESSING          506             350.2996      3
    MADISON COUNTY         103     M7 TRANS/PYROLYSIS     507             189.4999      3
    MONROE COUNTY          104     M6 PROCESSING          506              25.1000      3
    ST. CHARLES COUNTY     105     M9 TRANS               509             195.3000      3
    ST. CLAIR COUNTY       106     M7 TRANS/PYROLYSIS     507             636.0994      3
    ST. LOUIS CITY         107     M6 PROCESSING          506            1070.2996      3
    ST. LOUIS COUNTY       108     M6 PROCESSING          506            1582.2000      3
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                          ACTIVITY DATA FOR MODEL PERIOD 3

      TRANSPORTATION ACTIVITY LEVEL DATA FOR THE INTERMEDIATE TO INTERMEDIATE FACILITY PAIR(S)
                          *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

ORIGIN SITE NAME       I D   ORIGIN PROCESS NAME  I D    DESTINATION SITE NAME I D          ACTIVITY    MODEL
                                                                                            LEVEL *     PERIOD

M1 TRANS               501   TRANSFER PKR TO VAN  901    M6 PROCESSING         506           75.9000      3
M7 TRANS/PYROLYSIS     507   TRANSFER PKR TO VAN  901    M6 PROCESSING         506            0.0         3
M9 TRANS               509   TRANSFER PKR TO VAN  901    M6 PROCESSING         506          195.3000      3
M10 TRANS/PYROLYSIS    510   TRANSFER PKR TO VAN  901    M6 PROCESSING         506            0.0         3

                                          ACTIVITY DATA FOR MODEL PERIOD 3

                                            PROCESSING ACTIVITY LEVELS
                                  *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                                       ACTIVITY    MODEL
             SITE NAME             I D       PROCESS NAME        I D    LEVEL *    PERIOD

           M1 TRANS                501     TRANSFER PKR TO VAN   901     75.9000      3
           M6 PROCESSING           506     GAS PYROLYSIS         935   3447.5950      3
           M7 TRANS/PYROLYSIS      507     GAS PYROLYSIS         935    825.5989      3
           M9 TRANS                509     TRANSFER PKR TO VAN   901    195.3000      3
           M10 TRANS/PYROLYSIS     510     GAS PYROLYSIS         935      0.0         3
           U1 MKT/PROCESSING       514     SHREDDED FUEL/SEC RC  955      0.0         3
           A19 VIGUS QUARRY        711     SANITARY LANDFILL     907      0.0         3

                                       ACTIVITY DATA FOR MODEL PERIOD 3

                                        CAPACITY BUILDING ACTIVITY LEVELS
                                *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                                 MODEL           ACTIVITY  LINEAR
           SITE NAME          I D        PROCESS NAME       I D  PERIOD           LEVEL *  SEGMENT

         M6 PROCESSING        506     GAS PYROLYSIS         935    3             1220.6963     1
         A19 VIGUS QUARRY     711     SANITARY LANDFILL     907    3                0.0        1

                                          ACTIVITY DATA FOR MODEL PERIOD 3

                                        CAPACITY UNDERUTILIZATION ACTIVITY LEVELS
                                  *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                                  MODEL            ACTIVITY
             SITE NAME             I D       PROCESS NAME      I D  PERIOD             LEVEL *

           M6 PROCESSING           506     SHREDDED FUEL/SEC RC  955   3             2466.3992
           M9 TRANS                509     TRANSFER PKR TO VAN   901   3               75.7000
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                              ACTIVITY DATA FOR MODEL PERIOD 4

          TRANSPORTATION ACTIVITY LEVEL DATA FOR THE SOURCE TO INTERMEDIATE FACILITY PAIR(S)
                        *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                                    ACTIVITY     MODEL
       ORIGIN NAME         I D      DESTINATION NAME       I D        LEVEL *     PERIOD

     FRANKLIN COUNTY       101    M1  TRANS                501        98.8000      4
     JEFFERSON COUNTY      102    M6  PROCESSING           506       202.4000      4
     MADISON COUNTY        103    M7  TRANS/PYROLYSIS      507       702.2996      4
     MONROE COUNTY         104    M6  PROCESSING           506        34.8000      4
     ST. CHARLES COUNTY    105    M9  TRANS                509       271.0000      4
     ST. CLAIR COUNTY      106    M7  TRANS/PYROLYSIS      507       803.3997      4
     ST. LOUIS CITY        107    M6  PROCESSING           506      1205.3997      4
     ST. LOUIS COUNTY      108    M6  PROCESSING           506      2005.0020      4
     ST. LOUIS COUNTY      108    M10 TRANS/PYROLYSIS      510        37.1976      4

                              ACTIVITY DATA FOR MODEL PERIOD 4

  TRANSPORTATION ACTIVITY LEVEL DATA FOR THE INTERMEDIATE TO INTERMEDIATE FACILITY PAIR(S)
                        *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

ORIGIN SITE NAME      I D    ORIGIN PROCESS NAME  I D    DESTINATION SITE NAME I D          ACTIVITY     MODEL
                                                                                             LEVEL *     PERIOD

M1  TRANS             501   TRANSFER PKR TO VAN   901    M10 TRANS/PYROLYSIS   510           98.8000      4
M7  TRANS/PYROLYSIS   507   TRANSFER PKR TO VAN   901    M6  PROCESSING        506            0.0         4
M9  TRANS             509   TRANSFER PKR TO VAN   901    M10 TRANS/PYROLYSIS   510          271.0000      4
M10 TRANS/PYROLYSIS   510   TRANSFER PKR TO VAN   901    M6  PROCESSING        506            0.0         4

                              ACTIVITY DATA FOR MODEL PERIOD 4

                                 PROCESSING ACTIVITY LEVELS
                        *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                                    ACTIVITY     MODEL
       SITE NAME           I D        PROCESS NAME         I D        LEVEL *     PERIOD

     M1  TRANS             501     TRANSFER PKR TO VAN     901        98.8000      4
     M6  PROCESSING        506     GAS PYROLYSIS           935      3447.5874      4
     M7  TRANS/PYROLYSIS   507     GAS PYROLYSIS           935      1505.6995      4
     M9  TRANS             509     TRANSFER PKR TO VAN     901       271.0000      4
     M10 TRANS/PYROLYSIS   510     GAS PYROLYSIS           935       406.9971      4
     U1  MKT/PROCESSING    514     SHREDDED FUEL/SEC RC    955         0.0         4
     A19 VIGUS QUARRY      711     SANITARY LANDFILL       907         0.0         4
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                              ACTIVITY DATA FOR MODEL PERIOD 4

                              CAPACITY BUILDING ACTIVITY LEVELS
                        *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                                MODEL          ACTIVITY  LINEAR
       SITE NAME           I D        PROCESS NAME         I D  PERIOD          LEVEL *  SEGMENT

   M1 TRANS                501    TRANSFER PKR TO VAN     901     4             98.5000     2
   M6 PROCESSING           505    SHREDDED FUEL/SEC RC    955     4              0.0        1
   M7 TRANS/PYROLYSIS      507    TRANSFER PKR TO VAN     901     4              0.0        1
   M7 TRANS/PYROLYSIS      507    GAS PYROLYSIS           935     4            680.0994     1
   M10 TRANS/PYROLYSIS     510    TRANSFER PKR TO VAN     901     4              0.0        1
   M10 TRANS/PYROLYSIS     510    GAS PYROLYSIS           935     4            406.9971     1
   U1 MKT/PROCESSING       514    SHREDDED FUEL/SEC RC    955     4              0.0        1


                     LAND CONSTRAINT ACTIVITY LEVELS OF SLACKS IN ACRE-FEET

                              SITE        ACTIVITY LEVEL
                               711           20000.0000


                                          DYNAMIC MODEL OUTPUT

                                        MODEL PERIOD INNER SORT

OBJECTIVE VALUE IS -178939.3750 IN THOUSANDS OF DOLLARS DISCOUNTED TO YEAR ONE INCLUDING ALL COSTS FROM LOADING OF PACKER TRUCKS.


                   TRANSPORTATION ACTIVITY LEVEL DATA FOR THE SOURCE TO ULTIMATE FACILITY PAIR(S)
                              *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                                        ACTIVITY     MODEL
        ORIGIN NAME        I D     DESTINATION NAME      I D             LEVEL *     PERIOD

      MADISON COUNTY       103     A19 VIGUS QUARRY      711               0.0          1
      MADISON COUNTY       103     A19 VIGUS QUARRY      711               0.0          3
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                TRANSPORTATION ACTIVITY LEVEL DATA FOR THE SOURCE TO INTERMEDIATE FACILITY PAIR(S)
                                 *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                                            ACTIVITY     MODEL
    ORIGIN NAME          I D      DESTINATION NAME          I D             LEVEL *      PERIOD

  FRANKLIN COUNTY        101     M1 TRANS                   501             39.1000        1
  FRANKLIN COUNTY        101     M1 TRANS                   501             50.8000        2
  FRANKLIN COUNTY        101     M1 TRANS                   501             75.9000        3
  FRANKLIN COUNTY        101     M1 TRANS                   501             98.8000        4
  JEFFERSON COUNTY       102     M6 PROCESSING              506             65.5000        1
  JEFFERSON COUNTY       102     M6 PROCESSING              506             90.6000        2
  JEFFERSON COUNTY       102     M6 PROCESSING              506            148.5000        3
  JEFFERSON COUNTY       102     M6 PROCESSING              506            202.4000        4
  JEFFERSON COUNTY       102     M10 TRANS/PYROLYSIS        510              0.0           1
  JEFFERSON COUNTY       102     M10 TRANS/PYROLYSIS        510              0.0           2
  JEFFERSON COUNTY       102     U1 MKT/PROCESSING          514              0.0           1
  JEFFERSON COUNTY       102     U1 MKT/PROCESSING          514              0.0           2
  MADISON COUNTY         103     M5 PROCESSING              505            280.0999        1
  MADISON COUNTY         103     M6 PROCESSING              506            350.2996        3
  MADISON COUNTY         103     M7 TRANS/PYROLYSIS         507              0.0           1
  MADISON COUNTY         103     M7 TRANS/PYRULYSIS         507            361.6995        2
  MADISON COUNTY         103     M7 TRANS/PYROLYSIS         507            189.4999        3
  MADISON COUNTY         103     M7 TRANS/PYROLYSIS         507            702.2996        4
  MONROE COUNTY          104     M5 PROCESSING              506             10.2000        1
  MONROE COUNTY          104     M6 PROCESSING              506             25.1000        3
  MONROE COUNTY          104     M6 PRUCESSING              506             34.8000        4
  MONROE COUNTY          104     M7 TRANS/PYROLYSIS         507             14.8000        2
  ST. CHARLES COUNTY     105     M6 PROCESSING              506             79.3000        1
  ST. CHARLES COUNTY     105     M9 TRANS                   509            114.6000        2
  ST. CHARLES COUNTY     105     M9 TRANS                   509            195.3000        3
  ST. CHARLES COUNTY     105     M9 TRANS                   509            271.0000        4
  ST. CLAIR COUNTY       106     M6 PRUCESSING              506            358.2000        1
  ST. CLAIR COUNTY       106     M7 TRANS/PYROLYSIS         507            449.0999        2
  ST. CLAIR COUNTY       106     M7 TRANS/PYROLYSIS         507            636.0994        3
  ST. CLAIR COUNTY       106     M7 TRANS/PYROLYSIS         507            803.3997        4
  ST. LOUIS CITY         107     M6 PROCESSING              506            795.2996        1
  ST. LOUIS CITY         107     M6 PROCESSING              506            895.5999        2
  ST. LOUIS CITY         107     M6 PROCESSING              506           1070.2996        3
  ST. LOUIS CITY         107     M6 PROCESSING              506           1205.3997        4
  ST. LOUIS COUNTY       108     M6 PROCESSING              506            838.7000        1
  ST. LOUIS COUNTY       108     M6 PROCESSING              506           1075.2996        2
  ST. LOUIS COUNTY       108     M6 PROCESSING              506           1582.2000        3
  ST. LOUIS COUNTY       108     M6 PROCESSING              506           2005.0020        4
  ST. LOUIS COUNTY       108     M10 TRANS/PYROLYSIS        510             37.1976        4
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          TRANSPORTATION ACTIVITY LEVEL DATA FOR THE INTERMEDIATE TO INTERMEDIATE FACILITY PAIR(S)
                            *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

ORIGIN SITE NAME       I D    ORIGIN PROCESS NAME  I D    DESTINATION SITE NAME I D          ACTIVITY     MODEL
                                                                                              LEVEL *     PERIOD

M1 TRANS               501    TRANSFER PKR TO VAN  901    M6 PROCESSING          506           39.1000       1
M1 TRANS               501    TRANSFER PKR TO VAN  901    M6 PROCESSING          506           50.8000       2
M1 TRANS               501    TRANSFER PKR TO VAN  901    M6 PROCESSING          506           75.9000       3
M1 TRANS               501    TRANSFER PKR TO VAN  901    M10 TRANS/PYROLYSIS    510           98.3000       4
M7 TRANS/PYROLYSIS     507    TRANSFER PKR TO VAN  901    M6 PROCESSING          506            0.0          1
M7 TRANS/PYROLYSIS     507    TRANSFER PKR TO VAN  901    M6 PROCESSING          506            0.0          2
M7 TRANS/PYROLYSIS     507    TRANSFER PKR TO VAN  901    M6 PROCESSING          506            0.0          3
M7 TRANS/PYROLYSIS     507    TRANSFER PKR TO VAN  901    M6 PROCESSING          506            0.0          4
M9 TRANS               509    TRANSFER PKR TO VAN  901    M6 PROCESSING          506            0.0          1
M9 TRANS               509    TRANSFER PKR TO VAN  901    M6 PROCESSING          506          114.6000       2
M9 TRANS               509    TRANSFER PKR TO VAN  901    M6 PROCESSING          506          195.3000       3
M9 TRANS               509    TRANSFER PKR TO VAN  901    M10 TRANS/PYROLYSIS    510          271.0000       4
M10 TRANS/PYROLYSIS    510    TRANSFER PKR TO VAN  901    M6 PROCESSING          506            0.0          1
M10 TRANS/PYROLYSIS    510    TRANSFER PKR TO VAN  901    M6 PROCESSING          506            0.0          2
M10 TRANS/PYROLYSIS    510    TRANSFER PKR TO VAN  901    M6 PROCESSING          506            0.0          3
M10 TRANS/PYROLYSIS    510    TRANSFER PKR TO VAN  901    M6 PROCESSING          506            0.0          4
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PROCESSING ACTIVITY LEVELS

*ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR.

SITE NAME	I D	PROCESS NAME	I D	ACTIVITY LEVEL *	MODEL PERIOD
M1 TRANS	501	TRANSFER PKR TO VAN	901	39.1000	1
M1 TRANS	501	TRANSFER PKR TO VAN	901	50.3600	2
M1 TRANS	501	TRANSFER PKR TO VAN	901	75.9000	3
M1 TRANS	501	TRANSFER PKR TO VAN	901	98.8600	4
M6 PROCESSING	506	GAS PYROLYSIS	935	2226.3937	2
M6 PROCESSING	506	GAS PYROLYSIS	935	3447.5950	3
M6 PROCESSING	506	GAS PYROLYSIS	935	3447.5874	4
M6 PROCESSING	506	SHREDDED FUEL/SEC RC	955	2466.3992	1
M7 TRANS/PYROLYSIS	507	TRANSFER PKR TO VAN	901	0.0	1
M7 TRANS/PYROLYSIS	507	TRANSFER PKR TO VAN	901	0.0	2
M7 TRANS/PYROLYSIS	507	GAS PYROLYSIS	935	825.5989	2
M7 TRANS/PYROLYSIS	507	GAS PYROLYSIS	935	825.5989	3
M7 TRANS/PYROLYSIS	507	GAS PYROLYSIS	935	1505.6995	4
M9 TRANS	509	TRANSFER PKR TO VAN	901	0.0	1
M9 TRANS	509	TRANSFER PKR TO VAN	901	114.6000	2
M9 TRANS	509	TRANSFER PKR TO VAN	901	195.3600	3
M9 TRANS	509	TRANSFER PKR TO VAN	901	271.0000	4
M10 TRANS/PYROLYSIS	510	TRANSFER PKR TO VAN	901	0.0	1
M10 TRANS/PYROLYSIS	510	TRANSFER PKR TO VAN	901	0.0	2
M10 TRANS/PYROLYSIS	510	GAS PYROLYSIS	935	0.0	2
M10 TRANS/PYROLYSIS	510	GAS PYROLYSIS	935	0.0	3
M10 TRANS/PYROLYSIS	510	GAS PYROLYSIS	935	406.9971	4
U1 MKT/PROCESSING	514	SHREDDED FUEL/SEC RC	955	0.0	1
U1 MKT/PROCESSING	514	SHREDDED FUEL/SEC RC	955	0.0	2
U1 MKT/PROCESSING	514	SHREDDED FUEL/SEC RC	955	0.0	3
U1 MKT/PROCESSING	514	SHREDDED FUEL/SEC RC	955	0.0	4
A19 VIGUS QUARRY	711	SANITARY LANDFILL	907	0.0	1
A19 VIGUS QUARRY	711	SANITARY LANDFILL	907	0.0	2
A19 VIGUS QUARRY	711	SANITARY LANDFILL	907	0.0	3
A19 VIGUS QUARRY	711	SANITARY LANDFILL	907	0.0	4

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                          CAPACITY BUILDING ACTIVITY LEVELS
                    *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                              MODEL          ACTIVITY  LINEAR
      SITE NAME          I D        PROCESS NAME         I D  PERIOD          LEVEL *  SEGMENT

M1  TRANS                501     TRANSFER PKR TO VAN     901    1             75.9000     2
M1  TRANS                501     TRANSFER PKR TO VAN     901    4             98.8000     2
M6  PROCESSING           506     GAS PYROLYSIS           935    2           2226.8987     1
M6  PROCESSING           506     GAS PYROLYSIS           935    3           1220.6963     1
M6  PROCESSING           506     SHREDDED FUEL/SEC RC    955    4              0.0        1
M6  PROCESSING           506     SHREDDED FUEL/SEC RC    955    1           2466.3992     3
M7  TRANS/PYROLYSIS      507     TRANSFER PKR TO VAN     901    1              0.0        1
M7  TRANS/PYROLYSIS      507     TRANSFER PKR TO VAN     901    4              0.0        1
M7  TRANS/PYROLYSIS      507     GAS PYROLYSIS           935    2            825.5989     1
M7  TRANS/PYROLYSIS      507     GAS PYROLYSIS           935    4            680.0994     1
M9  TRANS                509     TRANSFER PKR TO VAN     901    1              0.0        1
M9  TRANS                509     TRANSFER PKR TO VAN     901    2            271.6000     3
M10 TRANS/PYROLYSIS      510     TRANSFER PKR TO VAN     901    1              0.0        1
M10 TRANS/PYROLYSIS      510     TRANSFER PKR TO VAN     901    4              0.0        1
M10 TRANS/PYROLYSIS      510     GAS PYROLYSIS           935    2              0.0        1
M10 TRANS/PYROLYSIS      510     GAS PYROLYSIS           935    4            406.9971     1
U1  MKT/PROCESSING       514     SHREDDED FUEL/SEC RC    955    1              0.0        1
U1  MKT/PROCESSING       514     SHREDDED FUEL/SEC RC    955    4              0.0        1
A19 VIGUS QUARRY         711     SANITARY LANDFILL       907    1              0.0        1
A19 VIGUS QUARRY         711     SANITARY LANDFILL       907    3              0.0        1

                          CAPACITY UNDERUTILIZATION ACTIVITY LEVELS
                    *ACTIVITY LEVELS ARE IN THOUSANDS OF TONS PER YEAR

                                                              MODEL             ACTIVITY
      SITE NAME          I D        PROCESS NAME         I D  PERIOD             LEVEL *

M1  TRANS                501     TRANSFER PKR TO VAN     901    1               36.8000
M1  TRANS                501     TRANSFER PKR TO VAN     901    2               25.1000
M6  PROCESSING           506     SHREDDED FUEL/SEC RC    955    2             2466.3992
M6  PROCESSING           506     SHREDDED FUEL/SEC RC    955    3             2466.3992
M9  TRANS                509     TRANSFER PKR TO VAN     901    2              156.4000
M9  TRANS                509     TRANSFER PKR TO VAN     901    3               75.7000


                 LAND CONSTRAINT ACTIVITY LEVELS OF SLACKS IN ACRE-FEET

                       SITE         ACTIVITY LEVEL
                        711          20000.0000
```
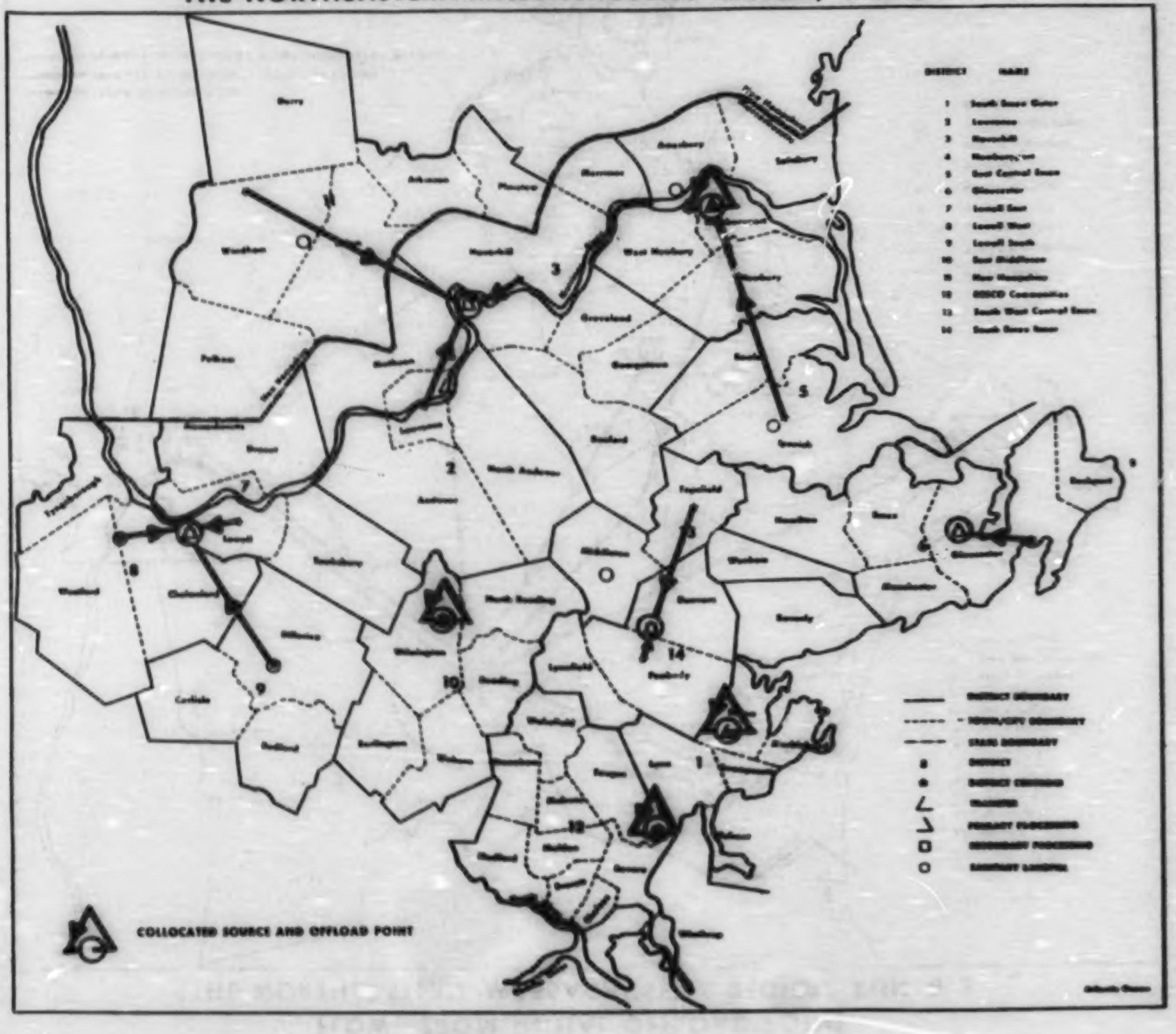

FLOWS TO INITIAL OFFLOAD POINT :
THE NORTHEASTERN MASSACHUSETTS REGION, RUN B-2


DISTRICT NAME
1 South Essex Outer
2 Lawrence
3 Haverhill
4 Newburyport
5 East Central Essex
6 Gloucester
7 Lowell East
8 Lowell West
9 Lowell South
10 East Middlesex
11 New Hampshire
12 ESSCO Communities
13 South West Central Essex
14 South Essex Inner
DISTRICT BOUNDARY
TOWN/CITY BOUNDARY
STATE BOUNDARY
DISTRICT
DISTRICT CENTROID
TRANSFER
PRIMARY PROCESSING
SECONDARY PROCESSING
SANITARY LANDFILL
COLLOCATED SOURCE AND OFFLOAD POINT
Derry
Windham
Pelham
Haverhill
Groveland
Georgetown
North Andover
Andover
Middleton
Carlisle
Peabody
Gloucester
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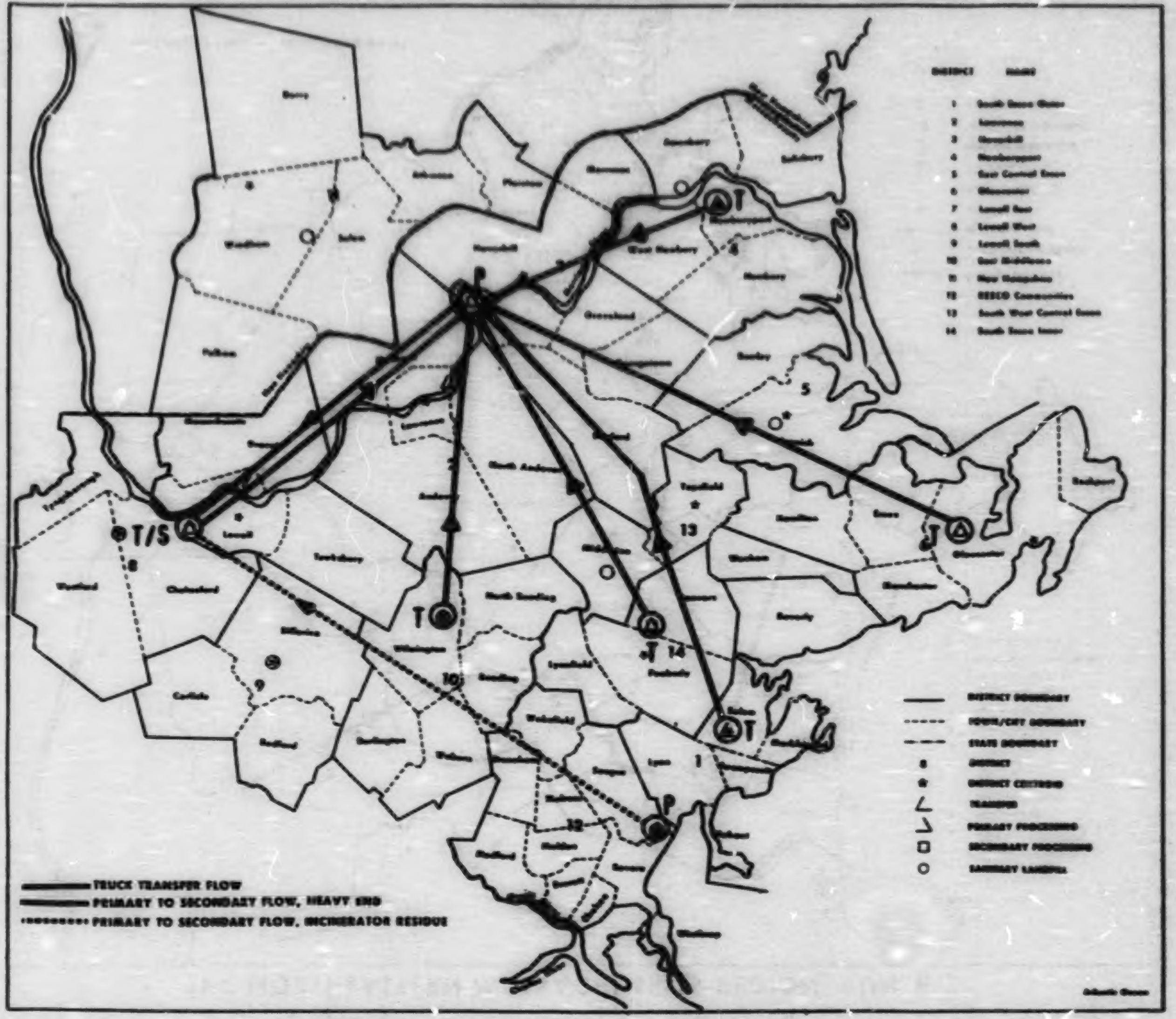
FLOWS FROM INITIAL OFFLOAD POINT :
THE NORTHEASTERN MASSACHUSETTS REGION, RUN B-2


DISTRICT NAME
1 South Essex Outer
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3 Haverhill
4 Newburyport
5 East Central Essex
6 Gloucester
7 Lowell East
8 Lowell West
9 Lowell South
10 East Middlesex
11 New Hampshire
12 RESCO Communities
13 South West Central Essex
14 South Essex Inner
DISTRICT BOUNDARY
TOWN/CITY BOUNDARY
STATE BOUNDARY
DISTRICT
DISTRICT CENTROID
TRANSFER
PRIMARY PROCESSING
SECONDARY PROCESSING
SANITARY LANDFILL
TRUCK TRANSFER FLOW
PRIMARY TO SECONDARY FLOW, HEAVY END
PRIMARY TO SECONDARY FLOW, INCINERATOR RESIDUE
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West Newbury
North Andover
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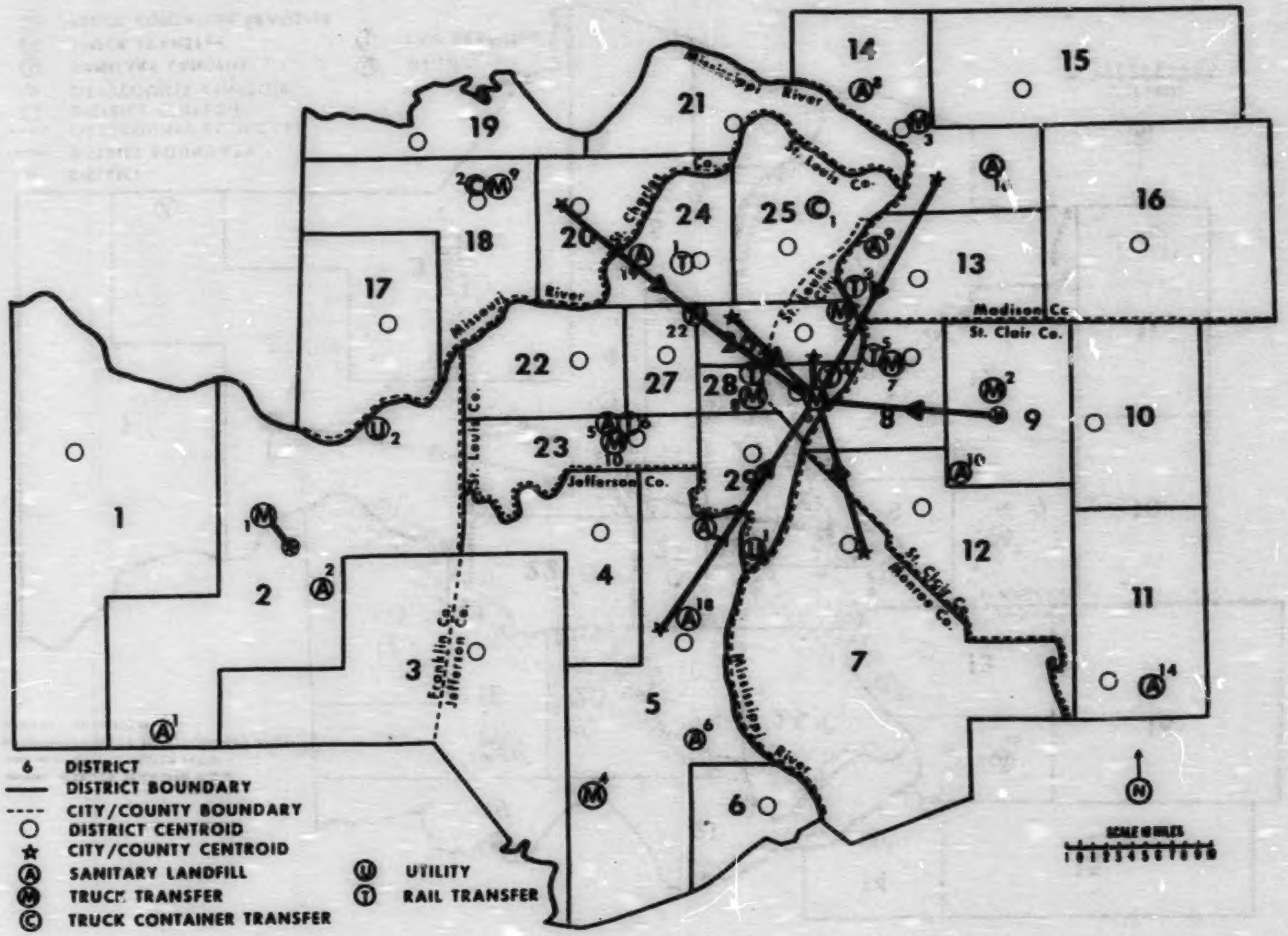
FLOWS TO INITIAL OFFLOAD POINT : THE ST. LOUIS REGION, RUN G-1st PERIOD


6 DISTRICT
DISTRICT BOUNDARY
CITY/COUNTY BOUNDARY
DISTRICT CENTROID
CITY/COUNTY CENTROID
SANITARY LANDFILL
TRUCK TRANSFER
TRUCK CONTAINER TRANSFER
UTILITY
RAIL TRANSFER
SCALE IN MILES
0 1 2 3 4 5 6 7 8 9 10
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Mississippi River
Missouri River
St. Charles Co.
St. Louis Co.
St. Louis City
Madison Co.
St. Clair Co.
Monroe Co.
Jefferson Co.
Franklin Co.
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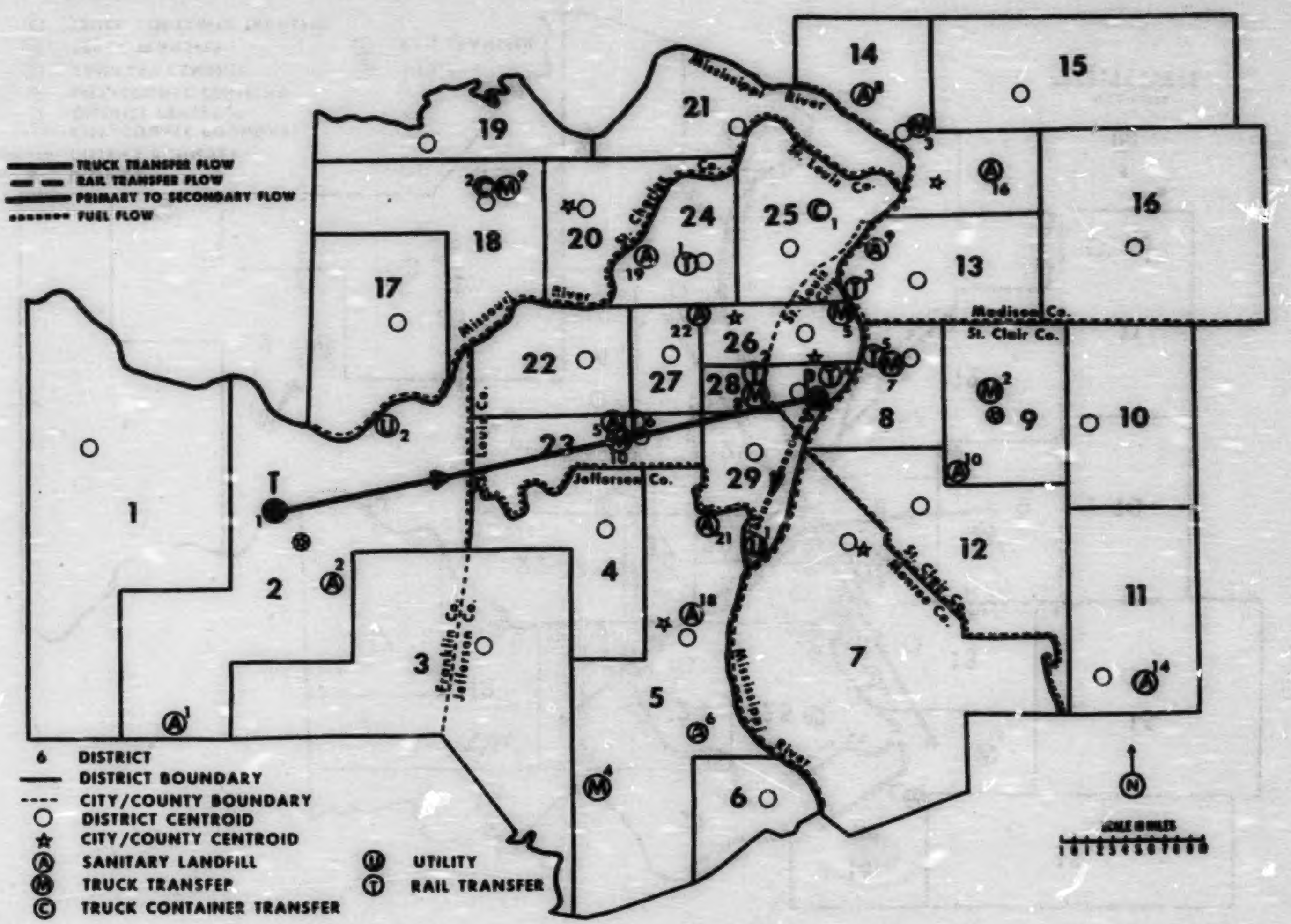
FLOWS FROM INITIAL OFFLOAD POINT : THE ST. LOUIS REGION, RUN G-1st PERIOD


TRUCK TRANSFER FLOW
RAIL TRANSFER FLOW
PRIMARY TO SECONDARY FLOW
FUEL FLOW
6 DISTRICT
DISTRICT BOUNDARY
CITY/COUNTY BOUNDARY
DISTRICT CENTROID
CITY/COUNTY CENTROID
SANITARY LANDFILL
TRUCK TRANSFEP
TRUCK CONTAINER TRANSFER
UTILITY
RAIL TRANSFER
Mississippi River
Missouri River
St. Charles Co.
St. Louis Co.
St. Louis City
Madison Co.
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Monroe Co.
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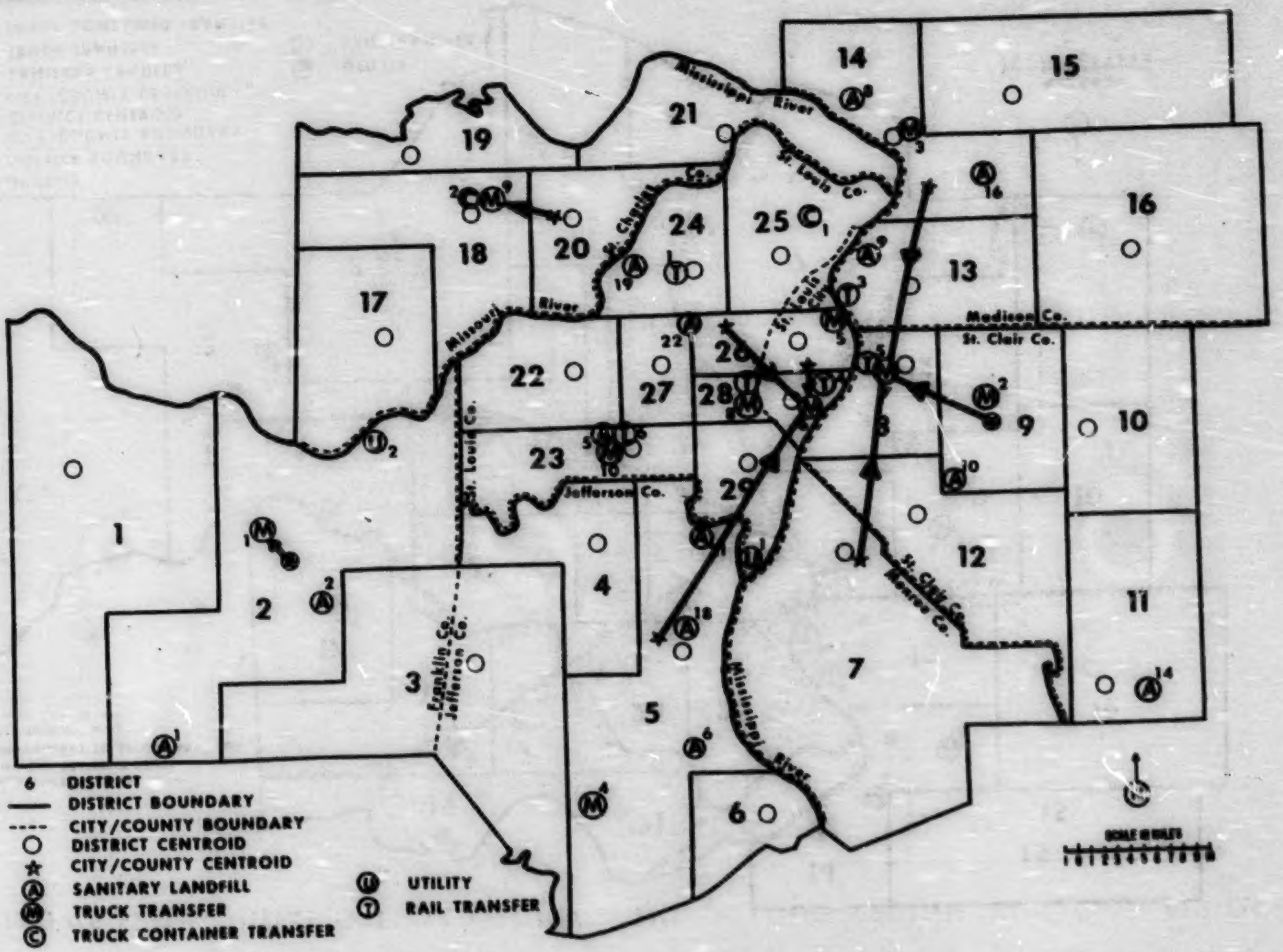
FLOWS TO INITIAL OFFLOAD POINT : THE ST. LOUIS REGION, RUN G-2nd PERIOD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St. Louis Co.
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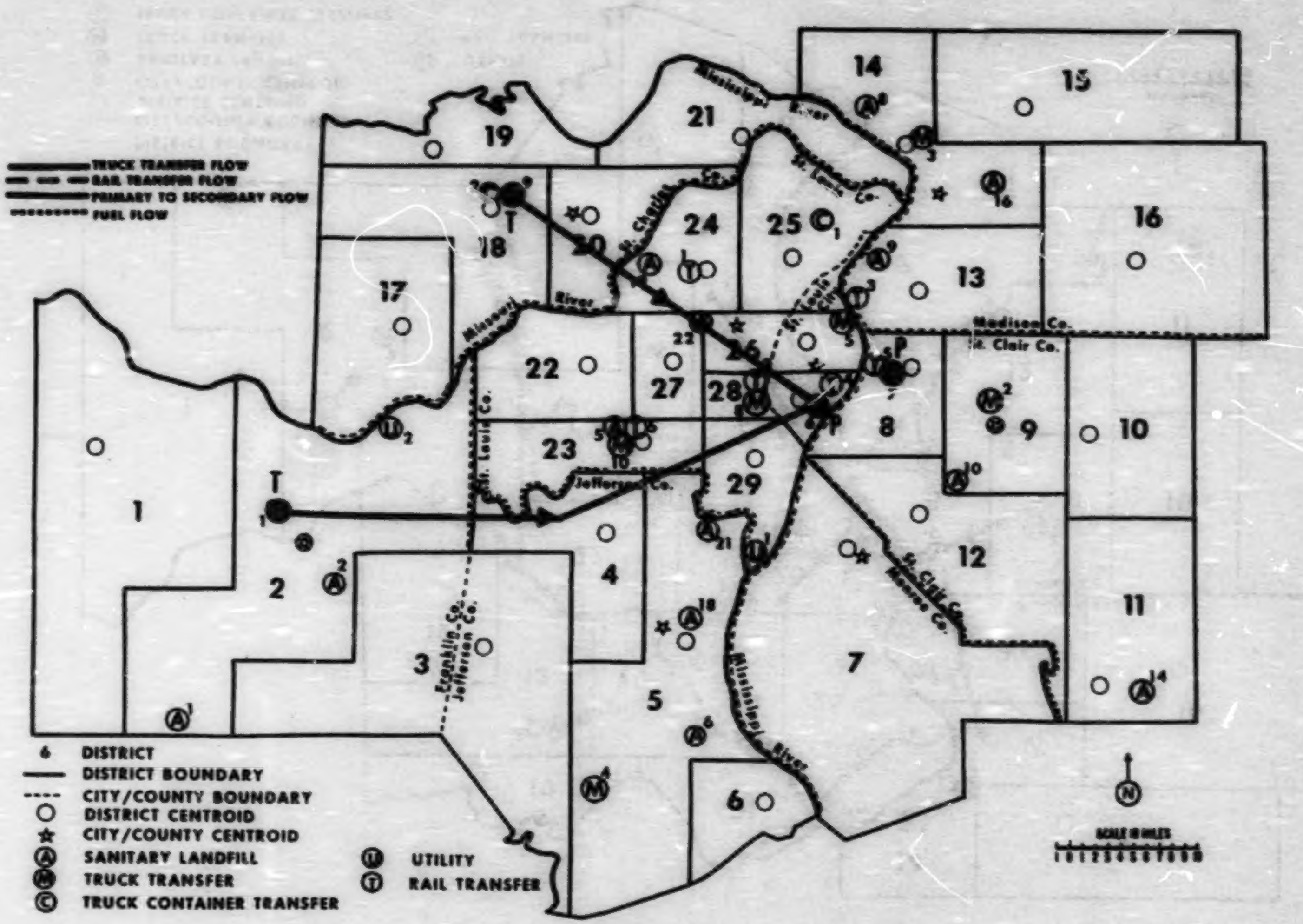
6 DISTRICT
DISTRICT BOUNDARY
CITY/COUNTY BOUNDARY
DISTRICT CENTROID
CITY/COUNTY CENTROID
SANITARY LANDFILL
TRUCK TRANSFER
TRUCK CONTAINER TRANSFER
UTILITY
RAIL TRANSFER
SCALE IN MILES
0 1 2 3 4 5 6 7 8 9 10

FLOWS FROM INITIAL OFFLOAD POINT : THE ST. LOUIS REGION, RUN G-2nd PERIOD


TRUCK TRANSFER FLOW
RAIL TRANSFER FLOW
PRIMARY TO SECONDARY FLOW
FUEL FLOW
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DISTRICT BOUNDARY
CITY/COUNTY BOUNDARY
DISTRICT CENTROID
CITY/COUNTY CENTROID
SANITARY LANDFILL
TRUCK TRANSFER
TRUCK CONTAINER TRANSFER
UTILITY
RAIL TRANSFER
Mississippi River
Missouri River
St. Charles Co.
St. Louis Co.
Madison Co.
St. Clair Co.
Monroe Co.
Jefferson Co.
Franklin Co.
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SCALE OF MILES
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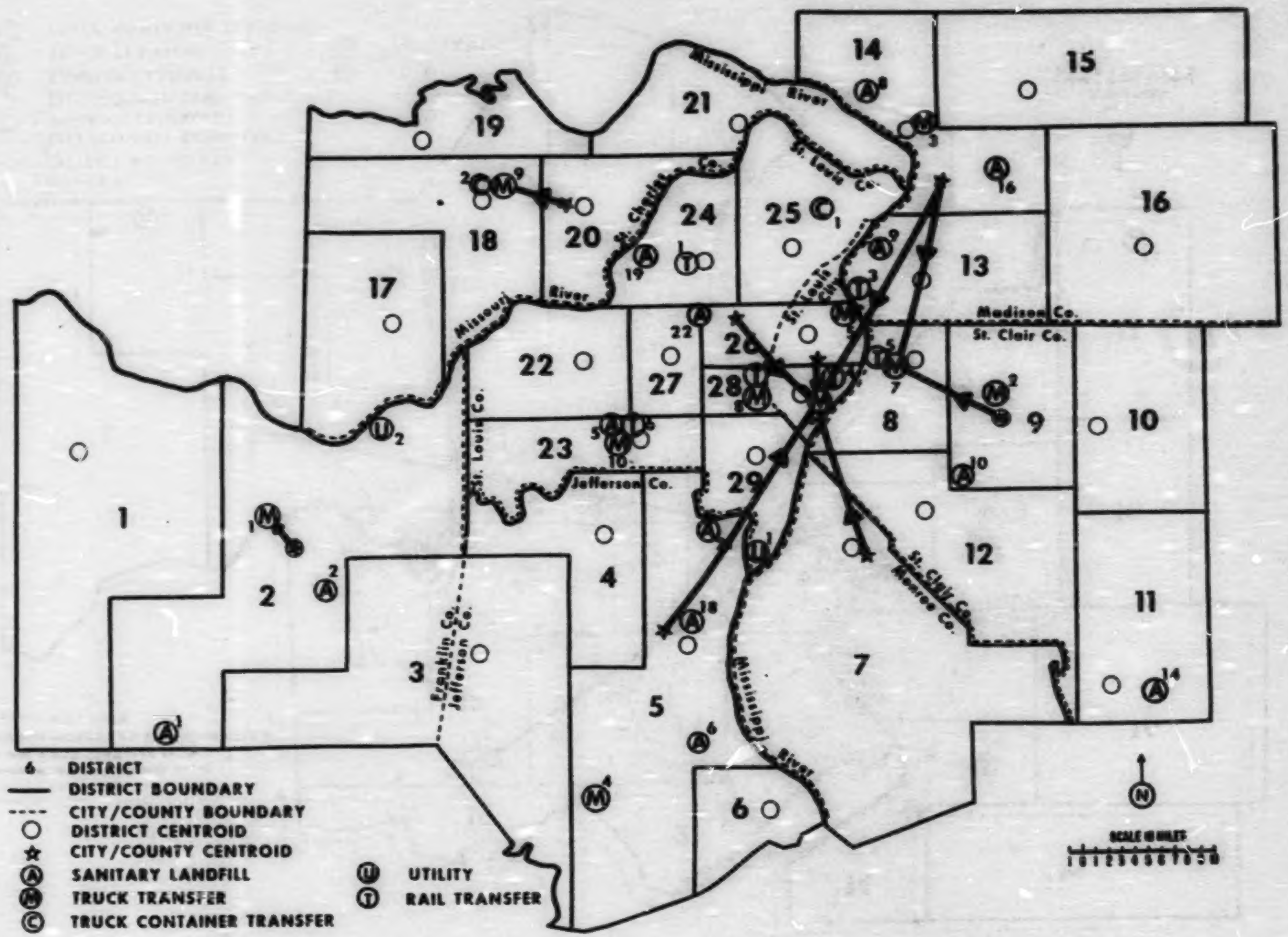
FLOWS TO INITIAL OFFLOAD POINT : THE ST. LOUIS REGION, RUN G-3rd PERIOD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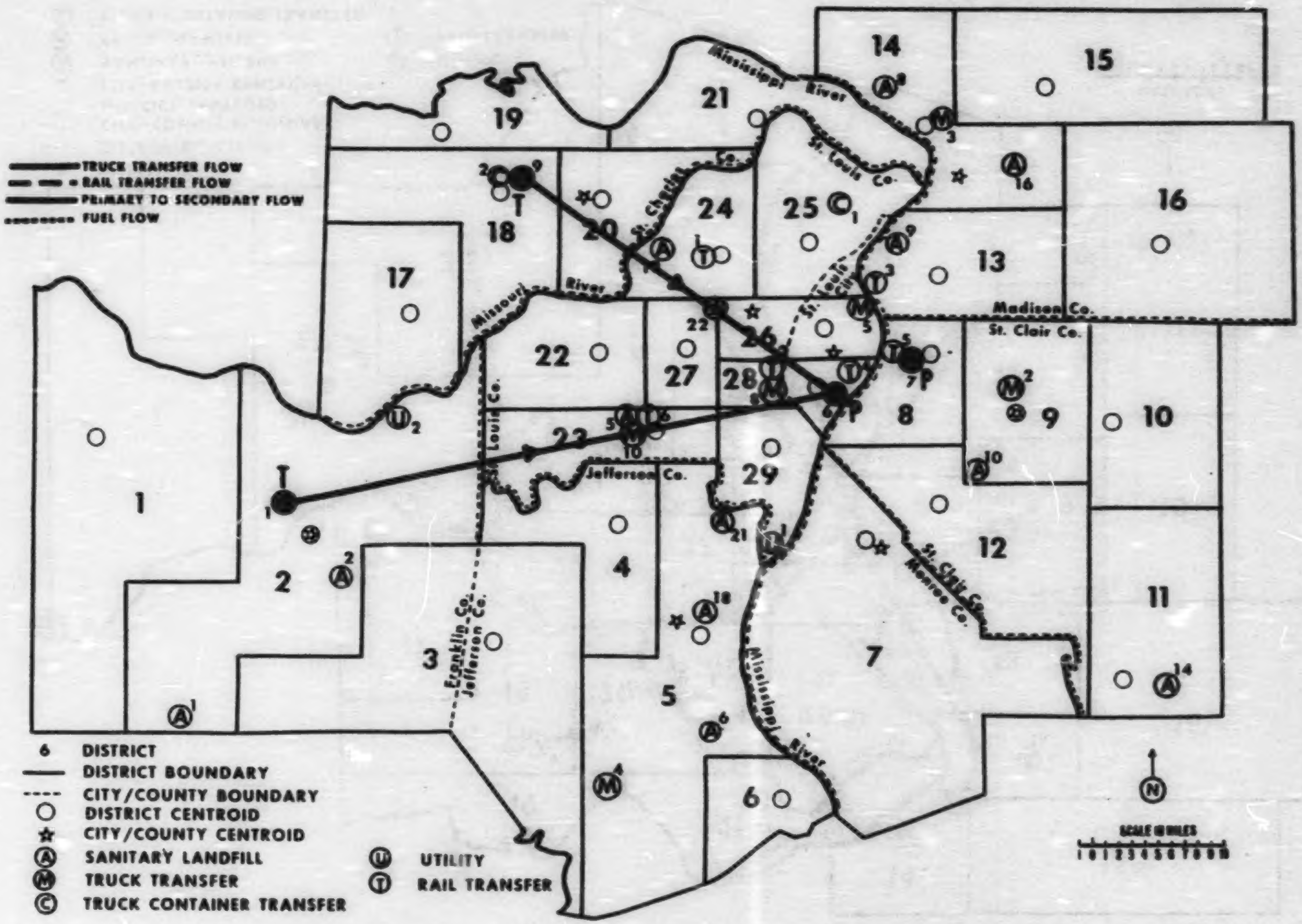
Mississippi River
Missouri River
St. Charles Co.
St. Louis Co.
St. Louis City
Madison Co.
St. Clair Co.
Monroe Co.
Jefferson Co.
Franklin Co.
N
SCALE IN MILES
6 DISTRICT
DISTRICT BOUNDARY
CITY/COUNTY BOUNDARY
DISTRICT CENTROID
CITY/COUNTY CENTROID
SANITARY LANDFILL
TRUCK TRANSFER
TRUCK CONTAINER TRANSFER
UTILITY
RAIL TRANSFER

FLOWS FROM INITIAL OFFLOAD POINT : THE ST. LOUIS REGION, RUN G-3rd PERIOD


TRUCK TRANSFER FLOW
RAIL TRANSFER FLOW
PRIMARY TO SECONDARY FLOW
FUEL FLOW
6 DISTRICT
DISTRICT BOUNDARY
CITY/COUNTY BOUNDARY
DISTRICT CENTROID
CITY/COUNTY CENTROID
SANITARY LANDFILL
TRUCK TRANSFER
TRUCK CONTAINER TRANSFER
UTILITY
RAIL TRANSFER
Mississippi River
Missouri River
St. Charles Co.
St. Louis Co.
St. Louis City
Madison Co.
St. Clair Co.
Monroe Co.
Jefferson Co.
Franklin Co.
SCALE IN MILES
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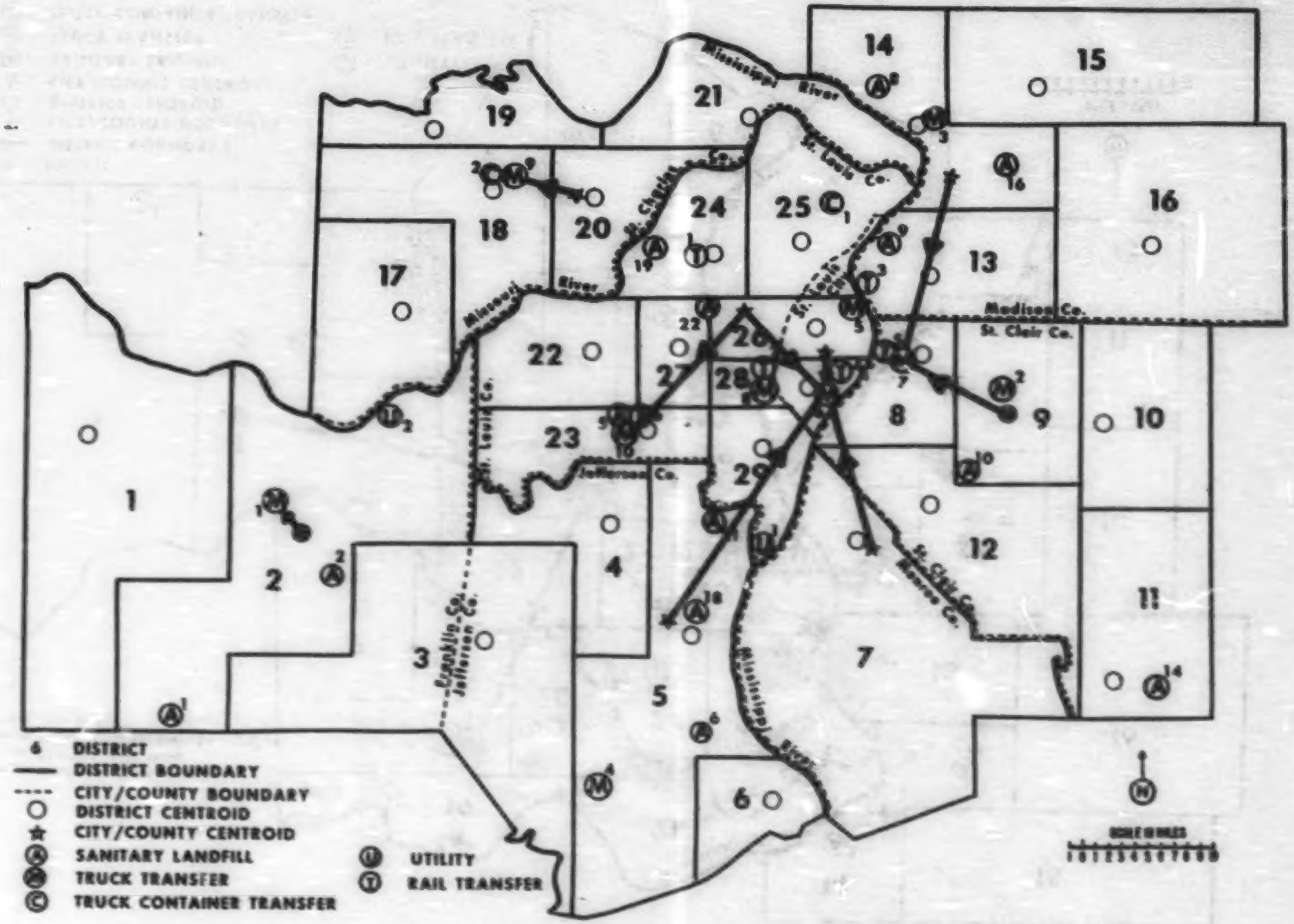
FLOWS TO INITIAL OFFLOAD POINT : THE ST. LOUIS REGION, RUN G-4th PERIOD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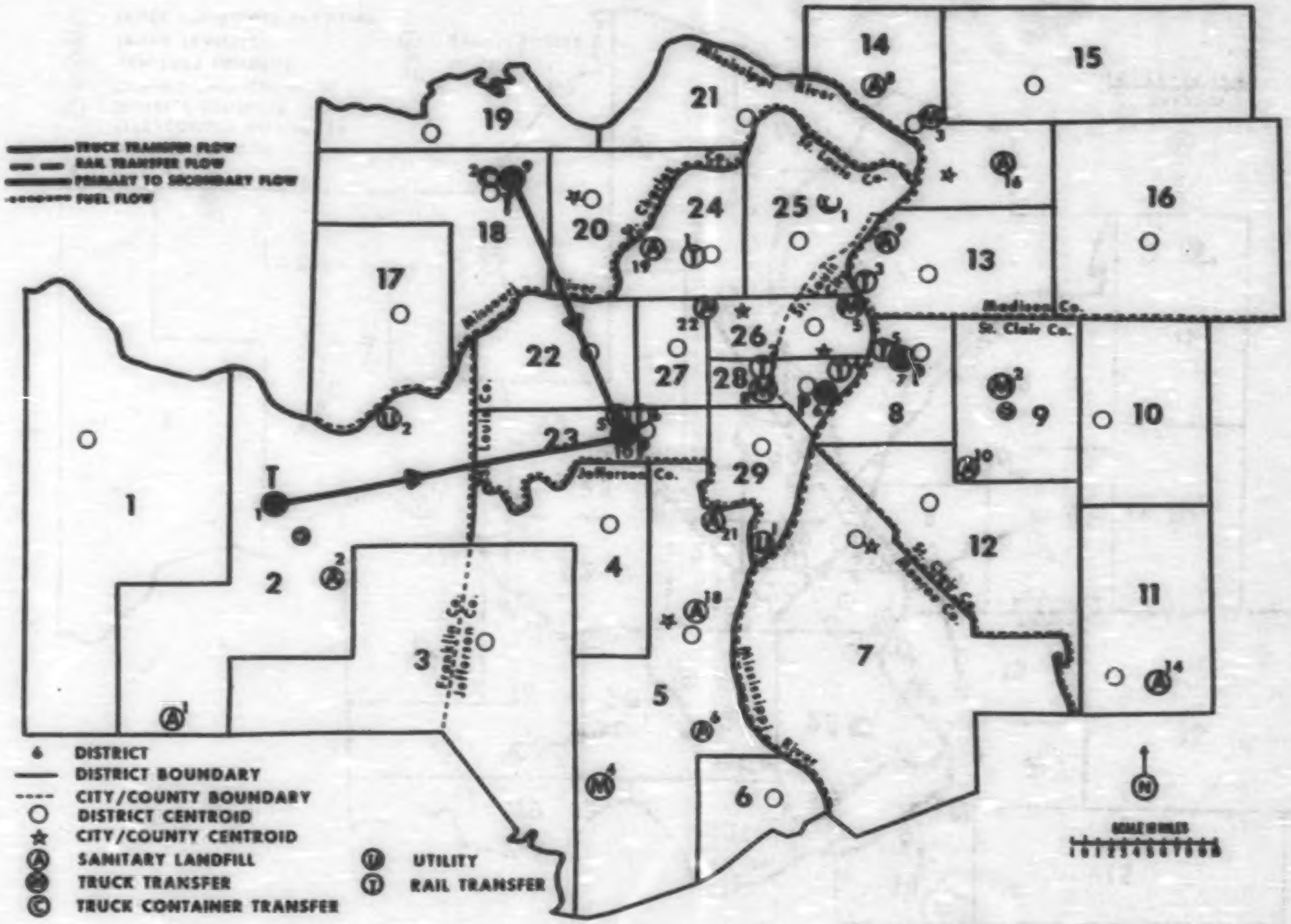
Mississippi River
Missouri River
St. Charles Co.
St. Louis Co.
St. Louis City
Madison Co.
St. Clair Co.
Monroe Co.
Jefferson Co.
Franklin Co.
6 DISTRICT
DISTRICT BOUNDARY
CITY/COUNTY BOUNDARY
DISTRICT CENTROID
CITY/COUNTY CENTROID
SANITARY LANDFILL
TRUCK TRANSFER
TRUCK CONTAINER TRANSFER
UTILITY
RAIL TRANSFER
SCALE-MILES
0 1 2 3 4 5 6 7 8 9 10

FLOWS FROM INITIAL OFFLOAD POINT : THE ST. LOUIS REGION, RUN G-4th PERIOD


TRUCK TRANSFER FLOW
RAIL TRANSFER FLOW
PRIMARY TO SECONDARY FLOW
FUEL FLOW
6 DISTRICT
DISTRICT BOUNDARY
CITY/COUNTY BOUNDARY
DISTRICT CENTROID
CITY/COUNTY CENTROID
SANITARY LANDFILL
TRUCK TRANSFER
TRUCK CONTAINER TRANSFER
UTILITY
RAIL TRANSFER
Mississippi River
Missouri River
St. Charles Co.
St. Louis Co.
Madison Co.
St. Clair Co.
Monroe Co.
Jefferson Co.
Franklin Co.
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CHAPTER 6

RUNNING TIMES EXPERIENCE

Table I displays, without comment, the sizes and running times of all the runs of the St. Louis Operational Test and the Massachusetts Exercise Program, together with information on whether a WRAP output was included and whether WRAP generated the starting basis. The running time was not available for N. E. Massachusetts run A.

Table 1

MODEL RUNNING TIMES

Run	Rows	Columns Without Slacks	Slacks	CPU Time, Seconds	Back End	Generated Starting Basis	Phase
St. Louis F	75	254	2	218.29	Yes	No	3
St. Louis G		Bridging Algorithm		57.23	Yes		NA
St. Louis G	115	287	2	811.71	No		3
St. Louis F-1	75	181	4	540.21	Yes		4
St. Louis A	90	325	9	432.97	Yes		3
St. Louis A-1	62	167	3	427.98	Yes		4
St. Louis C	61	146	3	211.71	Yes		3
St. Louis E	62	167	3	274.79	Yes		4
St. Louis B	112	512	20	363.16	No		3
St. Louis B-1	112	512	20	343.18	Yes		3
Mass. A	78	313	16	NA	No		3
Mass. A-2	60	148	7	270.05	No		4
Mass. A-3	60	148	7	53.18	No		3
Mass. A-4	60	148	7	68.52	Yes		3
Mass. B-1	60	148	7	238.32	Yes		4
Mass. B-2	60	148	7	186.82	Yes		4
Mass. C-1	60	148	7	274.20	Yes		4
Mass. C-2	60	148	7	261.76	Yes		4
Mass. C-3	60	148	7	322.09	Yes	No	4
Mass. D-1	60	149	7	149.65	Yes	Col. Z only	3
Mass. D-2	60	149	7	172.65	Yes	Yes with Col. Z	3
Mass. E-1	60	148	7	217.08	Yes	No	4
Mass. E-2	60	148	7	220.72	Yes	No	4

CHAPTER 7

GUIDANCE ON USING THE MODEL

In this chapter, the reader is asked to take a few steps backward and view the model from a somewhat broader context. The focus of the discussion here is not so much how to operate the model on a defined problem, but rather on how to define the problem itself. As a consequence the guidance to be provided is broader, less specific, relying more on the good judgement of the person using the model.

How to Structure An Application

An application is a set of runs designed to illuminate issues for the decision maker.

For a broader view of alternative mathematical structures, the reader is referred to the report of the original MITRE-sponsored design study, in which eighteen alternative model modes were presented.[2] All of these modes were designed to use the Walker Algorithm;[3] nine modes were static and nine were dynamic; and twelve had some capability of representing market saturation.

The reader might also gain insight from reviewing earlier model applications. In 1974, a basic static mode of the model (then called SWAMP, Solid WAste Management Planning) was used for a program of operational runs in support of regional design analysis for the Commonwealth of Massachusetts.[4] In these runs, the inputs to the algorithm were generated manually, and the outputs were interpreted manually.

The WRAP operational test in the St. Louis area and the Northeastern Massachusetts parametric exercise program have been fully reported in E. B. Berman, WRAP - A Model for Regional Solid Waste Management Planning: Documentation of Operational and Exercise Runs, MTR-3219, April 1976, which is available on request from The Environmental Protection Agency,

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[2] Berman, E. B. A model for selecting, sizing, and locating regional solid waste processing and disposal facilities. M73-111. Bedford, Mass., The MITRE Corporation, Oct. 1973. 61 p.

[3] Walker, W. Op. Cit.

[4] Berman, E. B., and H. J. Yaffe. Region design analysis for regional resource recovery system for northeastern Massachusetts. MITRE Technical Report MTR-2945. Bedford, Mass., The MITRE Corporation, Nov. 1974. 39 p.

Office of Solid Waste Management Programs, Systems Management Division, or from The MITRE Corporation.

In designing an application two things are important

- the modeling person should have a good understanding of how to put the model through its paces (note the subsection which follows, Controlling the Structure of the Solution)
- the model person should not attempt to design the complete application in advance. Some questions will arise from the solutions themselves. Time and budget should be allowed to answer them.

Illuminating Political and Technical Issues

An application, which is a set of runs, is designed to illuminate political and technical issues.

Each run in the set will:

- handle all wastes
- meet all environmental standards (for only processes which do meet relevant standards should be offered)
- provide the lowest cost solution for its "case".

The "case" is a defined state of political/technical feasibility. The case will define such things as:

which sites are available

which processes are available

which transportation activities are available (e.g., can these cross county or state lines), etc.

The model will generate a plan for each case, and a system cost for each case. This illuminates the incremental costs of moving from case to case, and in particular the costs of moving from less political acceptability to greater political acceptability. Figure 7 illustrates a hypothetical plan set. Figure 8 summarizes issues which have been examined in Massachusetts and in the St. Louis area.

Figure 3

THE PLAN SET

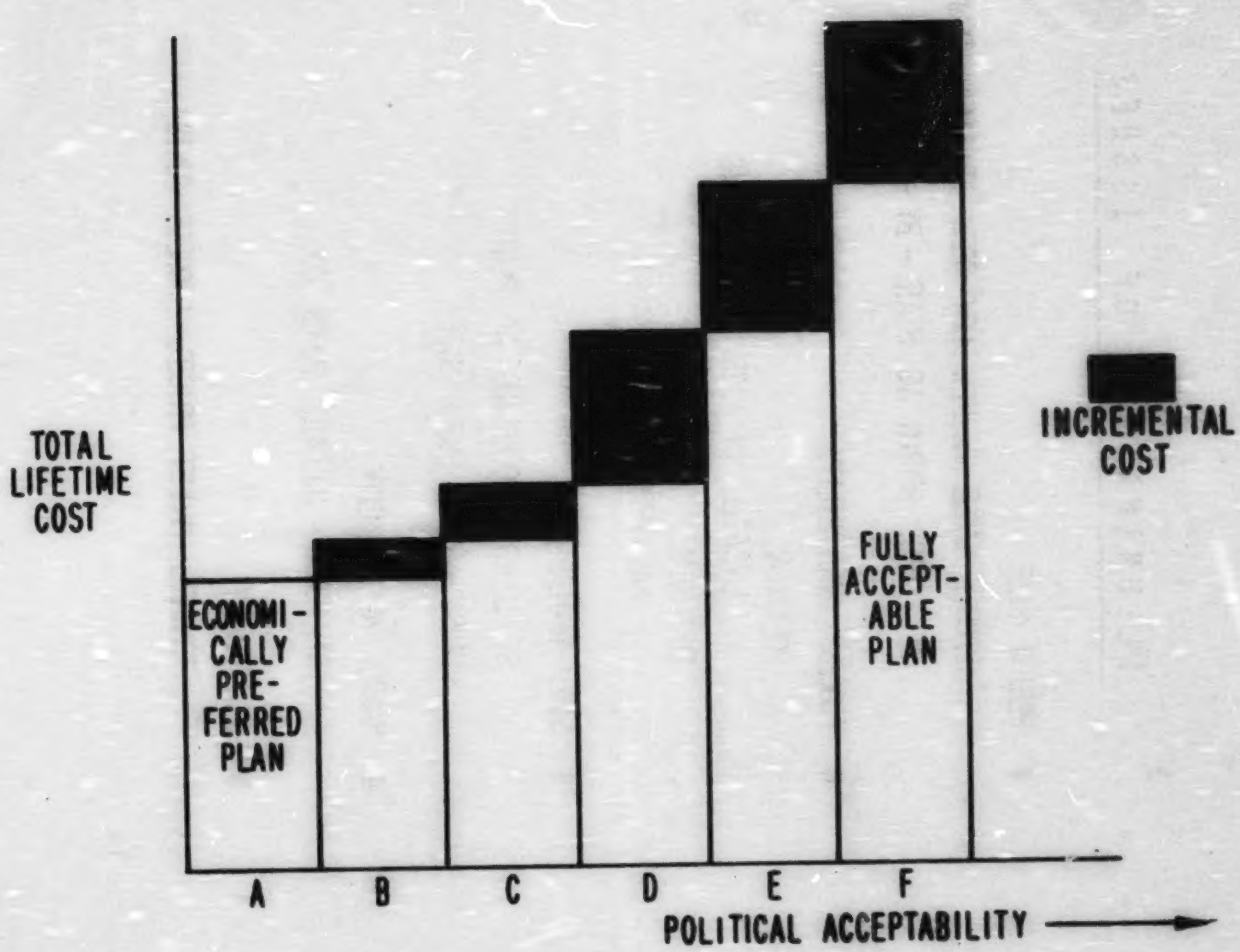

Figure 4

ILLUMINATION OF ISSUES

- REGION SIZE
    - MASS:: LARGE REGION: HOW DOES IT BREAK DOWN
    - ST. LOUIS: REGION VS STATE - BY - STATE
- PROCESS AVAILABILITY
    - POLITICAL
        - LANDFILL IN MASS. & ST. LOUIS
    - TECHNICAL
        - GAS PYROLYSIS IN MASS.
- SITE AVAILABILITY
    - ST. LOUIS - PROCESSING AT PLANT
    - MASS. - SOUTH ESSEX SITE
- MARKET AVAILABILITY
    - ST. LOUIS - ILLINOIS POWER CO.
- SENSITIVITY
    - TONNAGE, MARKET PRICES, PROCESS COSTS

Which Issues?

It is important that the modeling person communicate with the relevant decision-making group to learn what political and technical issues are important to them. It is essential for an interchange to be maintained between modeler and decision-maker as solutions are generated, as some issues are clarified, and as others are newly generated.

Controlling the Structure of the Solution (Configuration Forcing)

There are two general approaches to controlling the structure of the solution: (1) forcing the model to consider a structure or structural element (e.g., a site/process); and (2) forcing the model not to consider a structure or structural element. In the final analysis, the model can be made to consider a structure by forcing it not to consider all other structures.

The most direct way to get the model to consider a structure is to use that structure as an advanced starting point. If a costing of that structure is desired, the advanced starting point technique may not be sufficient since the model will move away from that structure if a better (i.e., lower cost) one can be found. For purposes of configuration forcing, however, it is important only that the model consider the structure, and the advanced starting point method is sufficient.

If the cost of a particular structure is desired, it would be more straightforward to eliminate enough other options to assure that the desired structure will be the solution.

The model can be made not to consider a structural element either by removing the structural element or by attaching an artifically high cost to it.

In the first series of Massachusetts runs, inputs were manually processed. It was simpler to attach an artificially high cost to processing activities which were not wanted in the solution, since in this way the matrix could be left unchanged. However, with WRAP, with its preprocessor, the cost vectors are less accessible, and at the same time, there is no disadvantage in needing a new matrix. Thus, for the St. Louis operational test and the Massachusetts exercise program, undesired structural elements were merely removed from the input.

The definition of region in the St. Louis series was controlled by the selection of transportation activities. Thus, run C of that series represented the case of no interstate flows (of raw refuse or heavy end residue). To accomplish this, the transportation file was screened, and all interstate activities were removed. Since each transportation activity is a single card in the transportation file, removal of such unwanted structural elements is easily accomplished.

The removal of a process at a site requires removal of the appropriate SIPROC card, and readjustment of the number of processes on the SITE card.

The user should be careful to readjust the appropriate count on the control card after removal of any structural element.

It should be noted that it is possible to remove a process from each site where it was offered without changing the process file, since there is no preprocessor check on whether a process in the file appears on a SIPROC card (indicating it is offered at a site). On the other hand, since linkage is checked, it is important in removing transportation activities to make sure that every site has at least one remaining input link and that every source and every site/process with positive percent output by weight has at least one remaining output link. If in doubt, CROW-FLY option 1 or 2 might be used.

How to Structure the Set of Sources

Ideally one would like to define a region into subregions (or zones, or districts) such that each had one and only one concentration of population (and hence waste generation) and such that there was a space of low population between the concentration and the subregion boundaries. Then the centroid of waste generation would be defined in the center of the concentration of population and would accurately represent the geographical impact of the waste generated in that subregion.

In real applications, we must compromise the ideal with what we find in the real world:

1. it is important to keep the size of the model small. Twenty-nine "districts" were defined for the static runs of the St. Louis Operational Test. We should not want to go much beyond that, and would prefer fewer. Fourteen "zones" were used for Massachusetts
2. inevitably, there are multiple concentrations of population in a subregion
3. inevitably, a concentration of population will spill over a subregional boundary.

It is suggested that the centroid of waste generation be defined for a subregion so as to represent the locational weight of population, and at the same time, if possible, to be at a major intersection past which a large volume of waste would tend to flow.

How to Structure the Set of Sites

Ideally, the set of sites would be:

1. real sites which are actually available to the solid waste planner
2. sufficient in number and sufficiently well spaced to allow the model to trade off freely between the economies of scale of centralization and the costs of haul required to support it.

In the real world, not enough sites will be nominated, and those will not be well spaced. It is recommended that additional sites be added by the user at key intersections in at least one run of the series to indicate how much additional system cost is implied by limiting the solution to sites actually available to the planner.

How to Strip Down a Problem for Optimization

It is desirable to make a large range of options available to the WRAP model so that a good solution can be found. However, it is also desirable to keep computer time and cost down to reasonable levels.

It is good practice to begin an application with one or more relatively large problems (in terms of the number of rows and columns) run through phase 3 in order to get some insight into the structure of the solution. The problem should then be stripped down to a smaller problem, with fewer rows and columns, which can then be run through phase 4 for full optimization. This smaller version can also be useful in reducing the size of subsequent configuration forcing runs. Note in Chapter 6 above the contrast in size been St. Louis A and B, and St. Louis A-1, which was the first run in the St. Louis series operated through phase 4. Similarly, in the Massachusetts exercise series, N. E. Mass. A was a large problem, operated through phase 3 only, and run A-2 was a stripped-down problem operated through phase 4. (Runs A-3 and A-4 were configuration forcing runs controlled by way of the advanced starting point, but operated only through phase 3.)

It should be noted that the time required to run using phase 4 is very sensitive to the number of columns since each additional column generates an additional forced solution and an additional phase 3 process. Thus it is important to strip out both columns and rows. Columns can be stripped by reducing the number of linear segments offered on the SIPROC; by removing many of the transportation activities; by removing some processes from some sites, and by removing some sites altogether. The latter two steps reduce the number of rows also. The number of rows can also be reduced by combining sources and by changing sites from limited to unlimited. All of these removals should be under the guidance of the phase 3 solution of the larger runs, but much care and thought is required to keep from constraining the model so much by the removal of options that it cannot find the best solution.

In one case, in the St. Louis series, two smaller runs were used to replace one larger run. Thus, St. Louis A offered primary processing in and near the central city (sites M5, M6, M7, and M10) and also at the utility sites (U1 and U2). Run A-1 offered only off-utility site processing (M5, M6, M7, and M10) and runs F and F-1 offered only on-utility site processing (U1 and U2). Thus the full range of options was preserved for locating primary processing, but not all in the same run.

Study of earlier applications of the model, as referenced at the beginning of this chapter, is recommended as a source of further insight into the operation of the model.

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